Vacuum Insulation for Window

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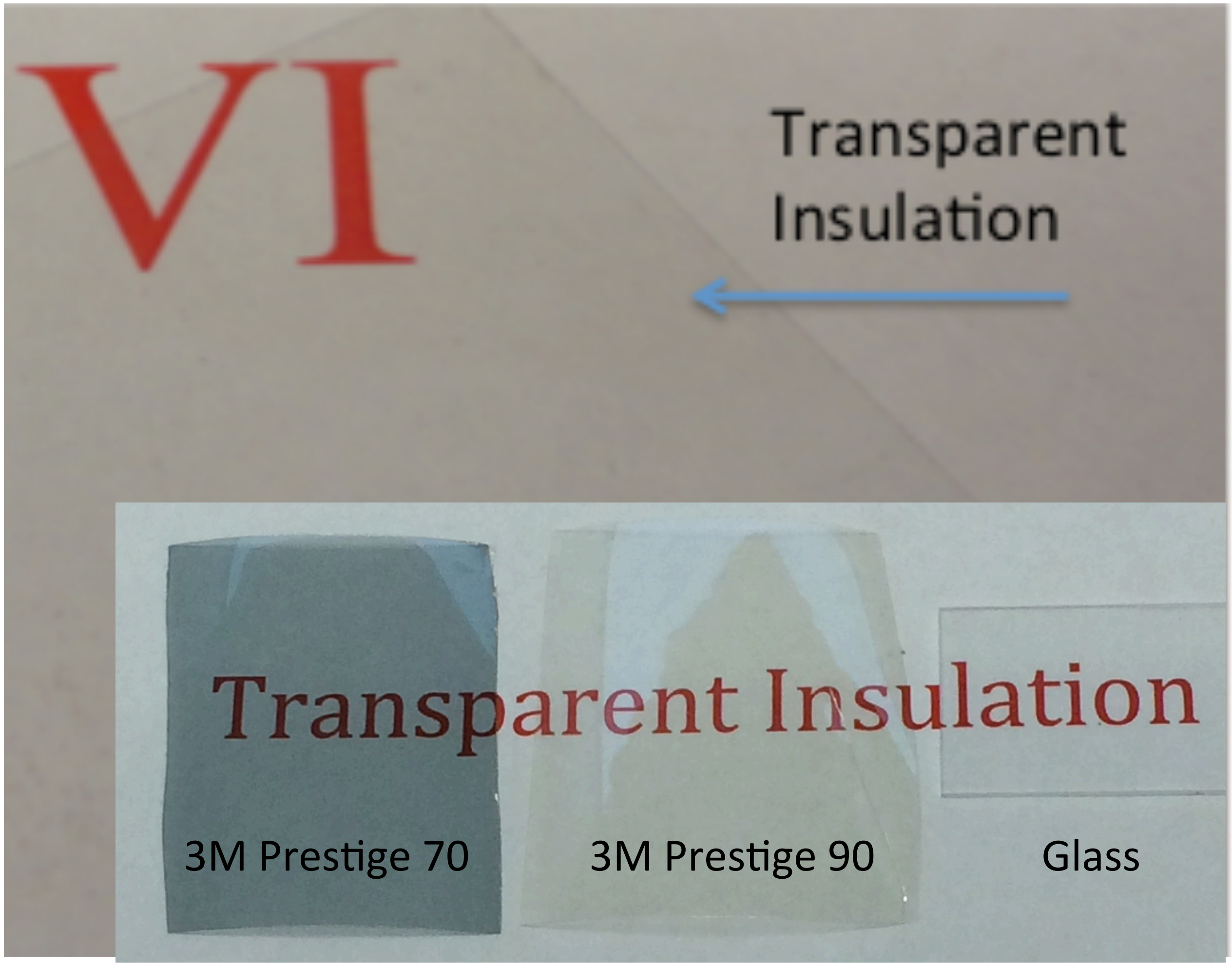

Pictures of NREL's transparent vacuum insulation for windows. The pictures show that the evacuated components are transparent while providing superior insulation in a flexible structure that can be retrofitted to installed windows.

Image of vacuum capsules on low-e coated films and glass, after multiple sprayed layers.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Nationa Renewabl Energ Laborator

Project Summary

Competively Selected Award FOA 823

Initial TRL 2: laboratory validation initial principles
Final TRL: 5: Reasonably realistic integration for testing

Timeline:

Start date: October 1, 2013

Planned end date: 2015

Key Milestones

1. Assess vacuum insulation materials with less than 0.007 W/m-K thermal conductivity; September 30, 2014
2. Deliver VI with low-e for external testing; September 30, 2015

Budget:

Total DOE $ to date: $750,000 FY14 & 15

Total future DOE $: $0

Target Market/Audience:

This effort addresses the large installed windows retrofit and inexpensive high performing new windows markets to substantially improve fenestration and building envelope energy efficiency.

Key Partners:

Engaging commercial companies that can provide key strategic alliances for manufacturing and specific market applications. Partners include vacuum capsule, low-e film, and window manufacturers.

Project Goal:

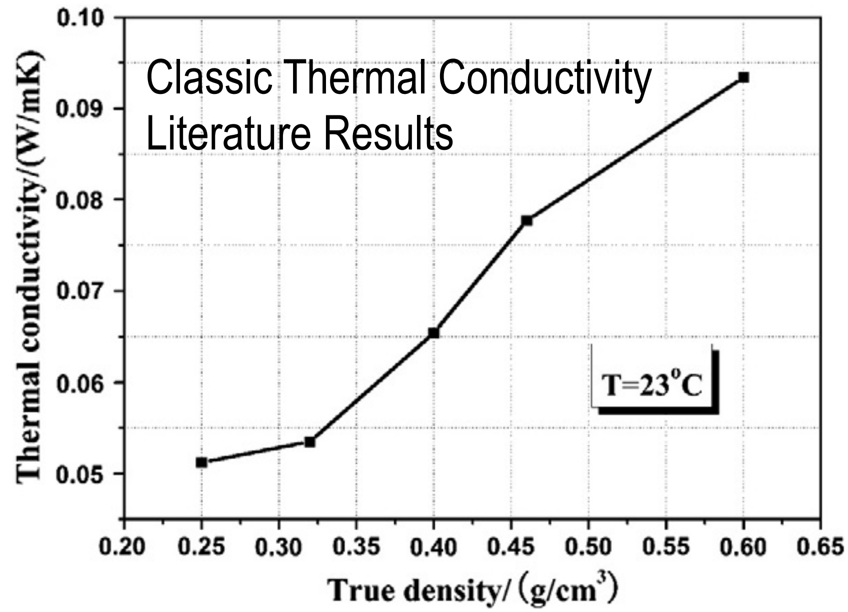
This effort is assessing the impact vacuum insulation (VI) will have for window applications using novel evacuated materials (that are so small as to be invisible) integrated with low-e coated plastic films. The ultimate goal is to develop materials that have R-5 to R-20 insulation values and have the correct form factor for easy integration with installed windows (i.e., flexible, thin, and applied like tinting products).

Purpose and Objectives

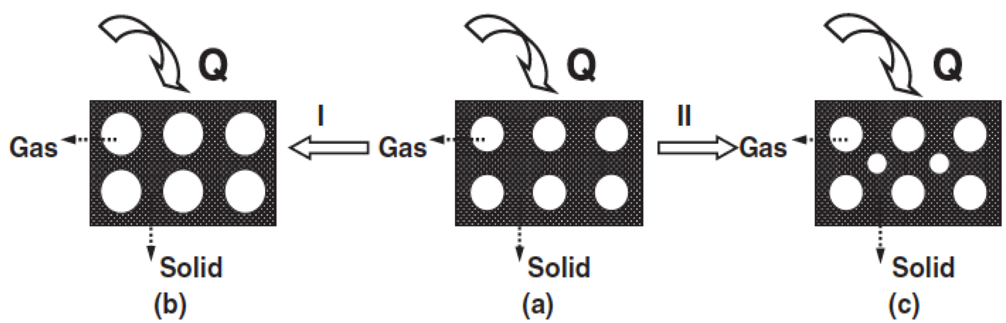
- **Problem Statement:** *Buildings use ~40% of the energy and produce ~40% of the CO_2 emissions in the United States (US) today*.
  - Windows can account for 30% to 50% of the energy losses in buildings.
    - It ***could take decades and trillions of dollars before replaced*** with highly insulating windows.
    - Thus substantial need for ***retrofitting*** installed windows to improve energy efficiency.
  - This effort is assessing vacuum insulation (VI) for window applications using novel evacuated materials (that are so small as to be invisible) integrated with low-e coated plastic films.
  - Goal: develop R-5 to R-20 insulation that has the correct form factor for easy integration with installed windows (i.e., flexible, thin, and applied like tinting products).
- **Target Market and Audience**: This effort addresses the large installed windows retrofit and inexpensive high performing new windows markets to substantially improve fenestration and building envelope energy efficiency.
  - Could save 1 to 3 quads of energy annually in US.
- **Impact of Project:** The project creates R-5 to R-20 transparent VI films that utilize nano- to micrometer sized vacuum capsules integrated with standard low-e coated flexible window plastics.
  - Near-term impact path: quantify insulation, transparency, cost, and other performance criteria to identify high-value market opportunities to support initial transition to commercial products.
  - Intermediate-term impact path: Work with commercialization partners to optimize manufacturing and performance for specific applications
  - Long-term impact path: Work with commercial and residential building communities to develop rapid market penetration strategies to help decrease energy use and CO_2 emissions as quickly as possible

Background: "Standard" Thermal Conductivity Calculations

- Calculated thermal conductivity of capsule materials using "standard" thermal dynamic assumptions
  - Assumes no radiative transport at 20 °C
  - For conduction only: through air & capsule material
  - Thermal conductivity directly related to the true density (ρ_t) of the capsules
    - $P_t = [1-(d/D)3]\ \rho 0$,
      - d is the average internal diameter,
      - D is the average external diameter, and
      - ρ0 is the density of shell part excluding hollow part



Typical assumption that thermal conductivity directly related to cross sectional area of solid material and air; **dominated by TC of solid material**.



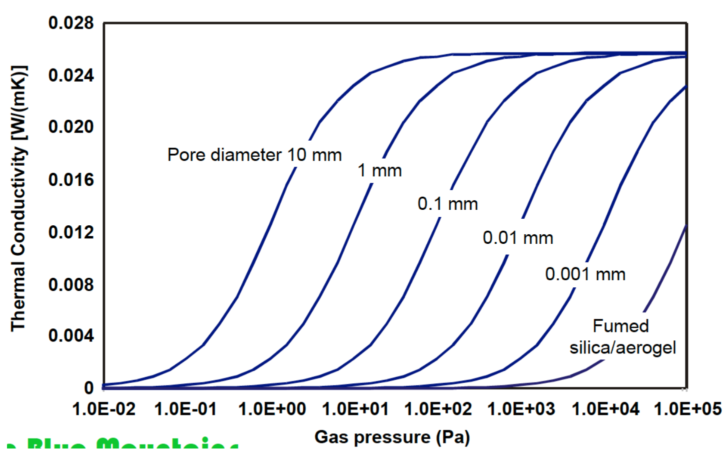
In effect, to reduce the TC of the system:
1. increase the ratio of d to D and
2. Increase the stacking coefficient of capsules, which also means to reduce the true density and increase the amount of capsules.

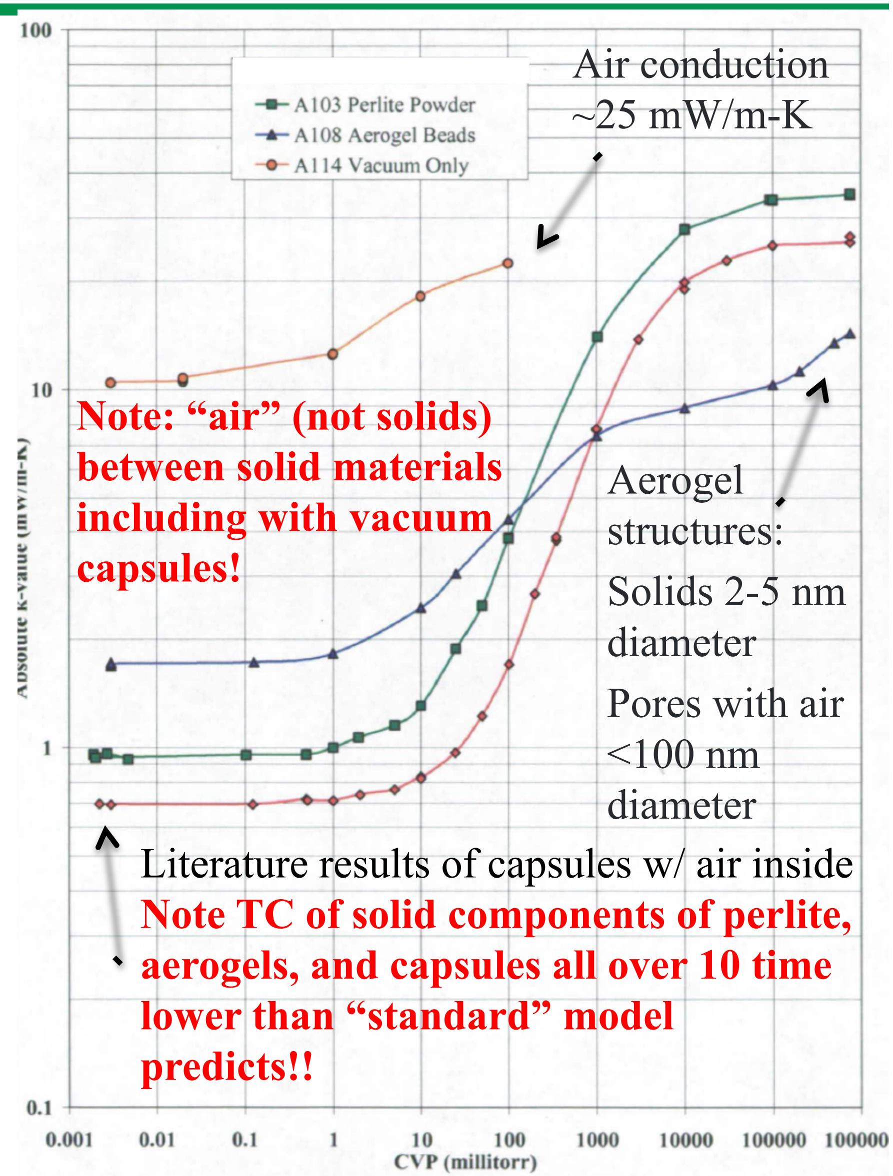
Overestimates Solids TC by >10X

Progress: Insulation Better Than Calculations & Vacuum, WHY!

- "Standard" TC assumptions:
  - Over-estimates solid conduction contribution.
  - **Wall thickness and amount of solid material not the issue**
  - Conduction through solid components bottle necked at small contact points.
    - True for most porous insulation
- Radiative and gas convective/conduction heat transport much larger in pure vacuum and open spaces than in insulating materials being developed for this project.
- Convection not applicable with small (micron) spaces
- Conduction through air largest component

Aerogel: Air conductivity (nanopore)
< Air conductivity (macropore)





NREL's Approach to Achieve High Insulation Values

- Use <100 nm sized vacuum capsules
  - Needed for transparency
  - Decreases pore sizes between capsules
- Decrease pore sizes with air to decrease air thermal short circuit.
  - Perhaps < 10 mW/m-K with capsules
- Evacuate capsules decrease TC
  - Perhaps < 5 mW/m-K
- Increase evacuated volume to >80%
  - Perhaps < 3 mW/m-K
- Low-e coatings to reduce IR
  - Perhaps < 1 mW/m-K
- Minimize capsule contact area
- Perhaps organic molecules used for self-assembly decreases conduction as well (i.e., Kapitza resistance, phonon interference)

In vacuum, point contacts between adjacent capsules have high thermal resistances

With air between capsules, effective TC that of air and capsule coupling

Note space between evacuated capsules is "air" not solid material!

Overall Approach: Use basic processes and materials to form smooth vacuum capsule layers with structure that minimizes thermal conductivity

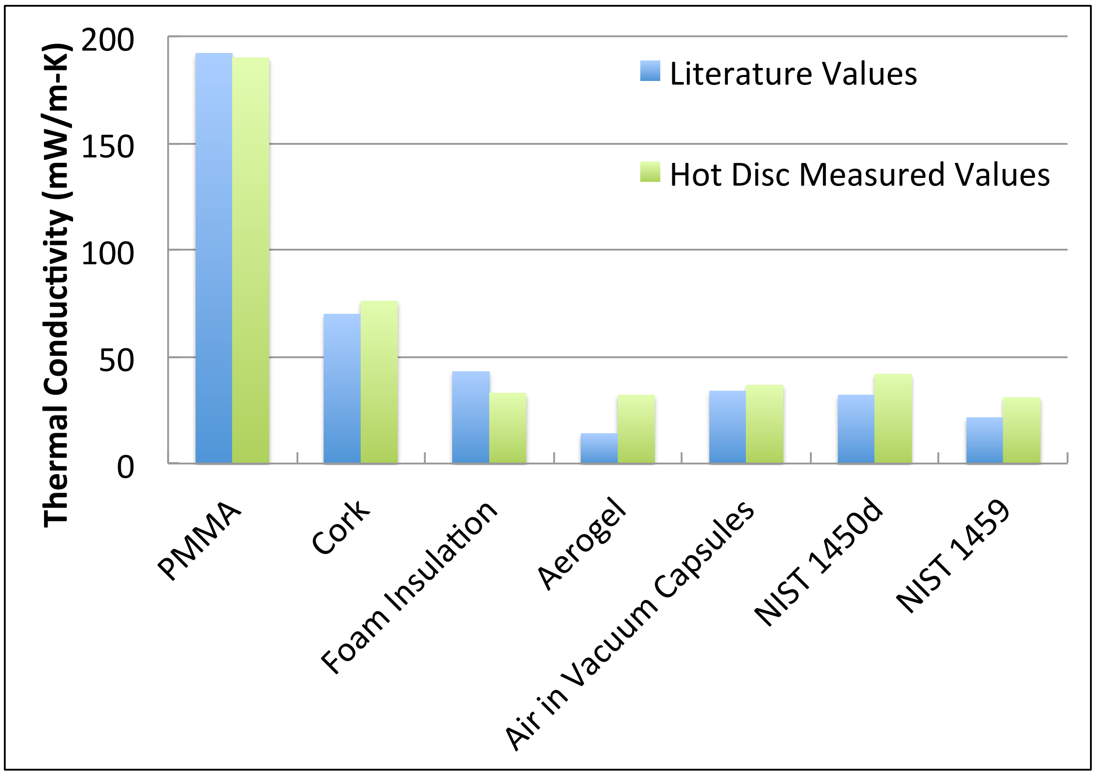
- Possibly maintain **thin flexible plastic sheets properties**.
  - **Inexpensive and scalable** to high throughput manufacturing.
- Demonstrate transparent R-5 to R-20 films

Key Issues: Thermal conductivity measurements below 20 mW/m-K

Distinctive Characteristics: Highly insulating transparent film will be a game changer for windows, resulting in substantial energy and CO_2 reductions

Progress: Ultra low TC Measurements an Issue

- Spent substantial time trying to accurately measure low TCs of porous materials
  - Hot Disc system provides reasonable TC values for standard non-porous materials
    - Measurement very reproducible, but "contact" issues with porous materials may be problem
  - Working with "NIST" standards and alternative measurements
  - Need to work through thin film versus bulk issues as well
  - Appears to give reproducible "relative" TC values to provide processing feedback

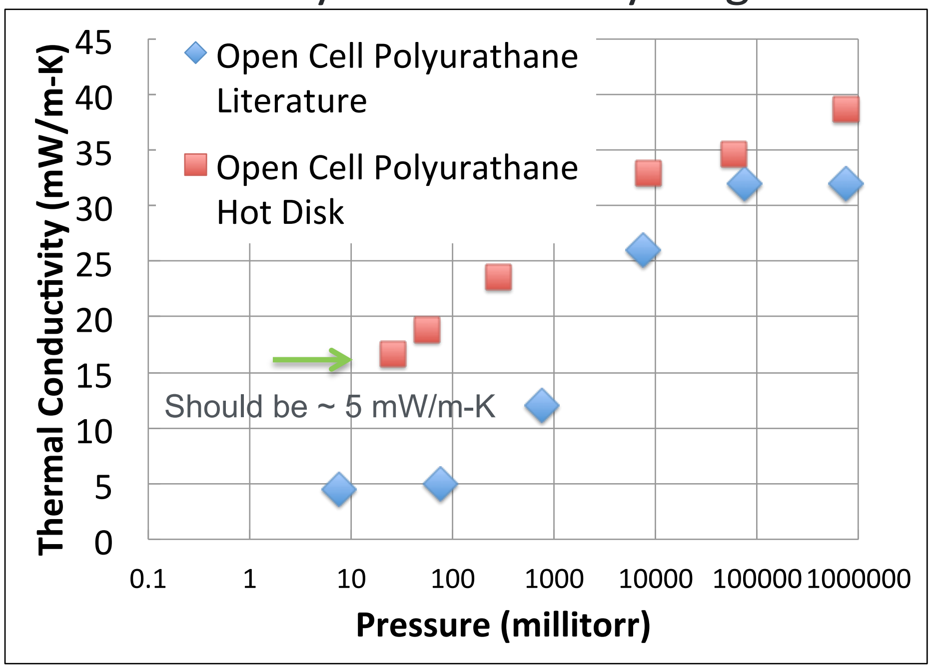


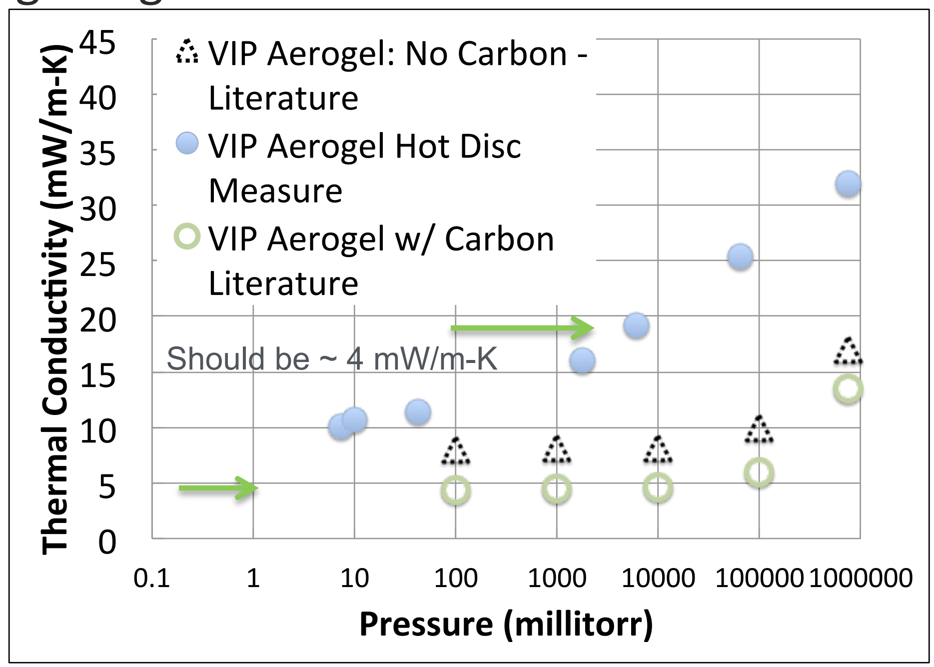
Hot disc overestimates the thermal conductivity of porous materials with air or vacuum in the open spaces between the solid materials by 10 mW/m-K or more.

May have more issues with materials that have smaller contact areas with sensor (e.g., vacuum capsules).

Accomplishment: Low Thermal Conductivity Measurements

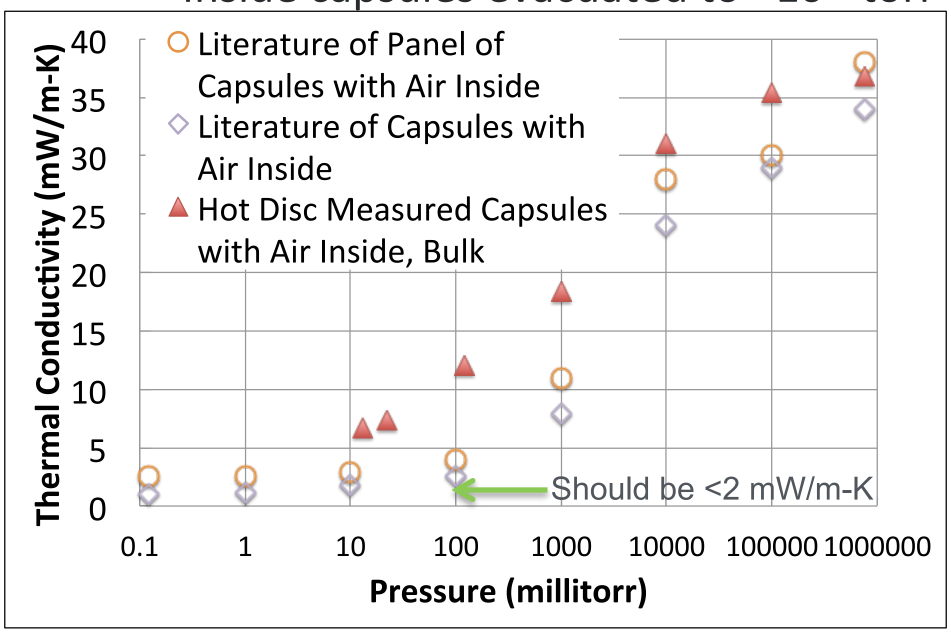
- Must go to evacuated materials to validate measurement systems to below 10 mW/m-K
  - Materials have lower thermal conductivity when air removed
  - Hot Disc systematically has higher measured TCs
    - Clearly overestimates TCs. All levels of vacuum?
    - Systematics may be good enough to get relative TC values

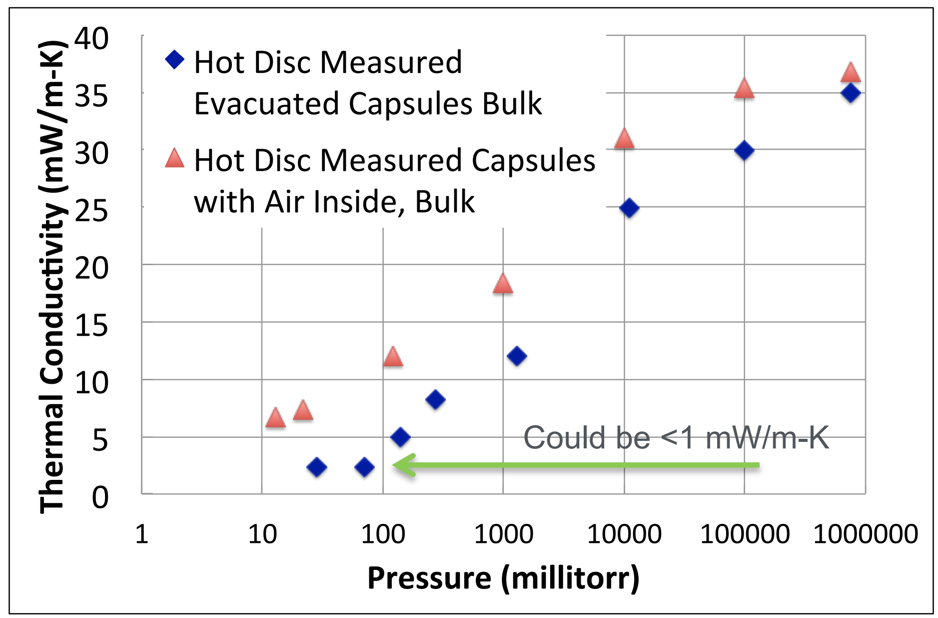




Accomplishment: NREL Vacuum Capsule Measurements

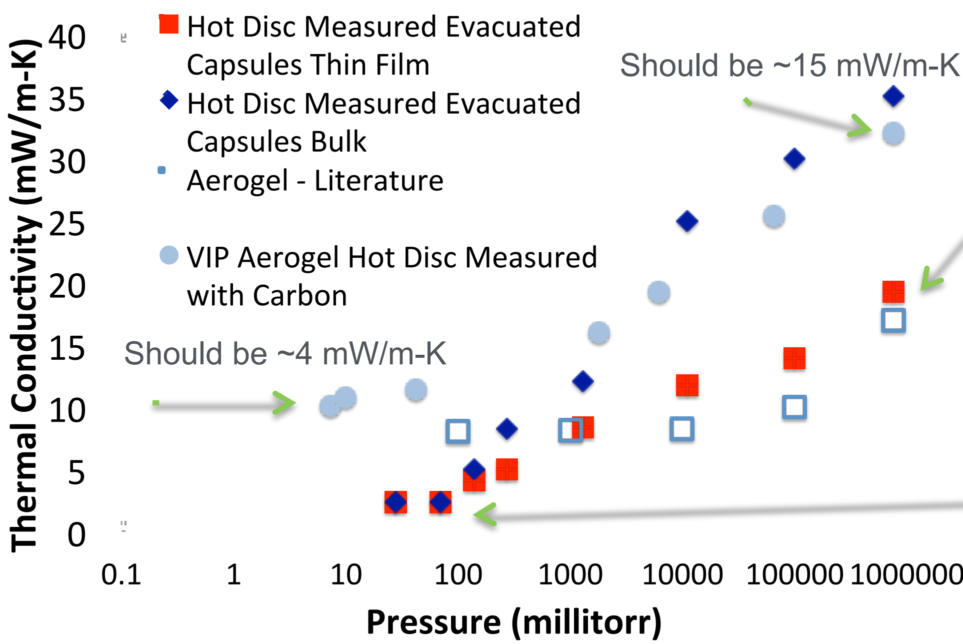
- NREL working to validate hot disc to very low thermal conductivity measurements (e.g., < 0.005 W/m-K).
- Hot Disc measurements of vacuum capsules are higher than literature values. (pressures in graphs are for outside the vacuum capsules)
- Clearly NREL's evacuated materials have lower TCs
  - As much as factor of 3 decrease in TC
  - Inside capsules evacuated to ~10^{-7} torr





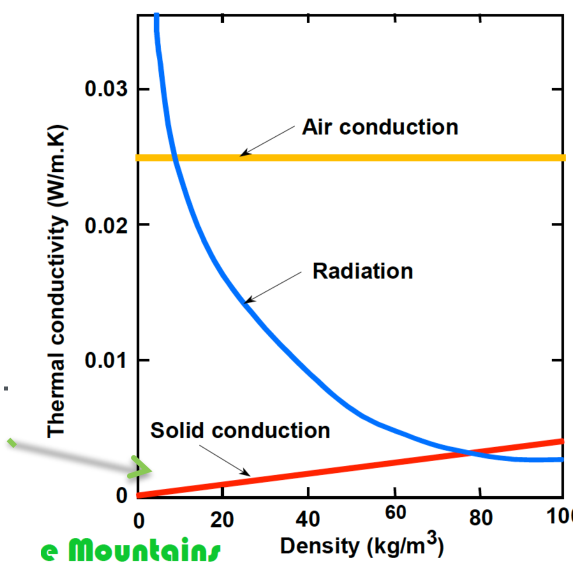
Accomplishment: NREL Vacuum Capsule Insulation

- **Vacuum capsule insulation 5 times better than aerogels or fumed silica.**
  - TC of solid vacuum capsule components less than 2 mW/m-K
  - Removing air from the inside of vacuum capsules reduces TC of capsules by factor of 3
  - With low-e coatings and good vacuums outside, capsules may achieve less than 1 mW/m-K
  - Need to confirm results with larger samples and heat flux instrument measurements
  - In general agreement with non-evacuated capsule literature results
- Reconciling "thin film" versus bulk measurement results.



Vacuum capsule TC with air on outside should go down with smaller and less pores

Results show TC of solid components very small. Agrees with aerogel results. Air between capsules main thermal leak.



Accomplishment: Increased Packing Densities to Reduce TC

- Work toward > 90% of volume under vacuum and/or semi-closed pores
- Work toward nanometer sized semi-closed pores to reduce gas thermal conductivity. Made:
  - "cylindrical" shaped capsules (~90% packing density)
  - "concaved" shapes capsules (<95% packing density)
  - "cubic" shaped capsules (~100% packing density)

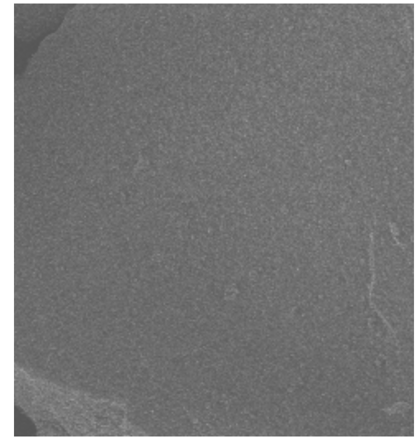


Image ~250 X 250 microns

NREL vacuum capsules form well packed stacks

Table of Packing Densities

Table 1: Densest Known Packings of Some Convex Particles

Particle	Packing Density	Central Symmetry	Equivalent Axis	Structure
Sphere	0.740	Y	Y	Bravais Lattice
Ellipsoid	0.740 - 0.770	Y	N	Periodic, 2-particle basis
Superball	0.740 - 1	Y	Y	Bravais Lattice
Tetrahedron	0.856	N	Y	Periodic, 4-particle basis
Icosahedron	0.836	Y	Y	Bravais Lattice
Dodecahedron	0.904	Y	Y	Bravais Lattice
Octahedron	0.945	Y	Y	Bravais Lattice
Trun. Tetrah.	0.995	N	Y	Periodic, 2-particle basis
Cube	1	Y	Y	Bravais Lattice

Stacked cylinders >90% packing Density

Accomplishments: NREL Achieved High Insulation Values

- ✓ Use ~100 nm sized vacuum capsules
  - Needed for transparency
  - Decreases pore sizes between capsules

Need to generate large enough samples (~6"X6") to perform TC measurements

- ✓ Decrease pore sizes with air to decrease air thermal short circuit.
  - Achieve < 10 mW/m-K with capsules
- ✓ Evacuate capsules decrease TC
  - Perhaps < 5 mW/m-K

Solid components less than 2 mW/m-K, need to focus on air on outside of vacuum capsules

- ✓ Increase evacuated volume
  - Perhaps < 3 mW/m-K

Need to form well organized layers of the different materials with the different shapes

- Low-e coatings to reduce IR
  - Perhaps < 1 mW/m-K

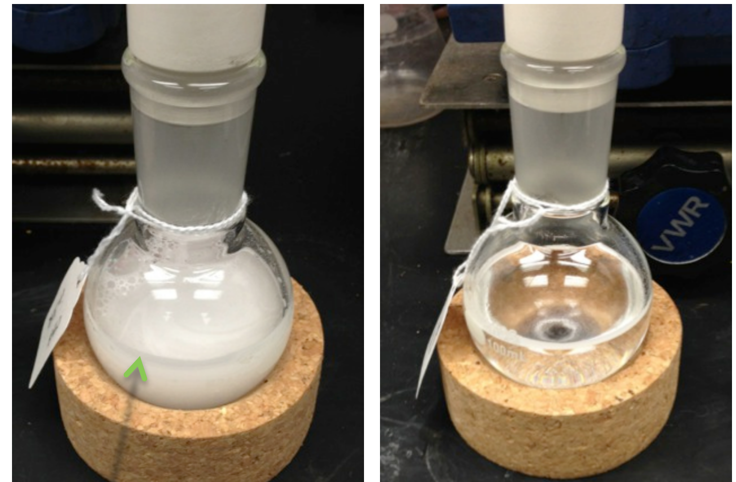
Future projects could look at vacuum capsules with integrated low-e coatings

- Minimize capsule contact area
- Perhaps organics used for self-assembly decreases conduction as well
  - i.e., Kapitza resistance

Will be done as part of the larger sample size testing

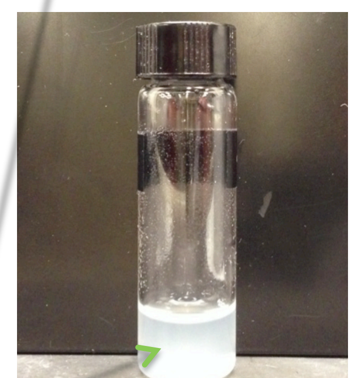
Accomplishment: Functionalization and Self-Assembly

- Capsule Functionalization and Assembly
  - Identified and tested vacuum capsule synthesis and layer integration methods to create suspensions that work
    - Note: after 24 hr some capsules settle to bottom
    - Suspension sufficient for different deposition techniques, including dip and lamination
  - These same techniques provide excellent stacking of vacuum capsules to form high quality optical coatings with limited voids
    - Limited stacking voids important
    - Use different suspension materials to tailor processes for transparency and insulation



Images of vacuum capsule suspensions right after mixing and 24 hours later

Image of Vacuum Capsules Deposited using Dip Coating, demonstrating virtually no visual degradation



Images of same vacuum capsules in water (4 mg/ml) used for dip coating.

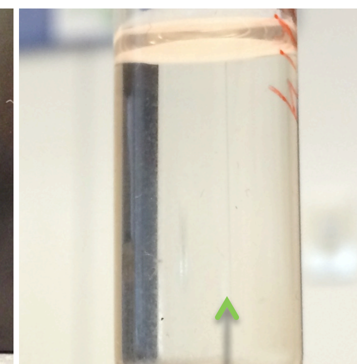


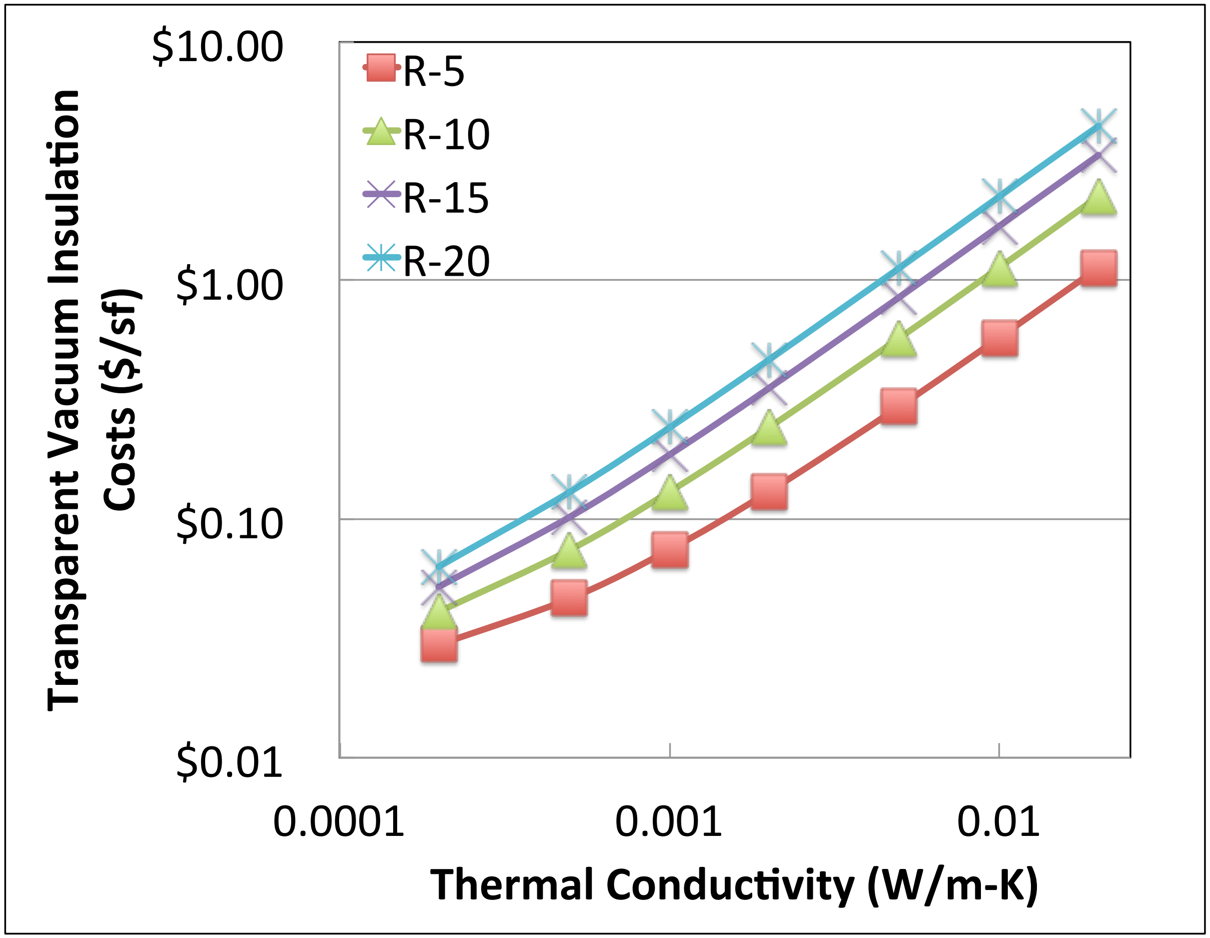
Image of vacuum capsules completely transparent (fully dispersed) in solution with no separation after weeks.

Accomplishment: Transparent Insulating Films

- Transparency
  - Solution (sol-gel) based process produces millimeter thick films w/ vacuum capsules similar to aerogels in transparency
  - Analog: Thick aerogels with “random” structures are transparent
  - Pores and structures smaller than wavelength of light, i.e., less than 100 nm
    - Reduces scattering and refraction
    - Investigate uniform structures to increase visible light transmission, reduce haze
- Processing amenable to roll-to-roll slot coater on flexible substrates
  - Manufacturing process development (chemistry) should proceed similar to aerogel/fumed silica use in vacuum insulate panels
  - Refractive Index of vacuum capsule films can be adjusted between 1 & 1.5
    - Air is ~1

Accomplishment: Window Vacuum Insulation Manufacturing Costs

- *Initial manufacturing cost estimates, demonstrating a simple payback of less than 5 years based on identified commercial processing.*
  - Need to put more fidelity into each processing step as it becomes more defined during the project.



- Simple pay back is 2 years: assumes
  - Average home has ~200 sf of windows.
  - $1/sf vacuum insulation means $200 for average house
  - 10% energy savings for average home with the window insulation on a $1000 per year utility bill.

This is a very good payback time that will motivate substantial numbers to enhance their window insulation to save hundreds of dollars per year

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Summary of Accomplishments

- Thermal Conductivity Principles
  - Vacuum capsules are second best insulating materials known/measured by NASA
  - Recent work validated initial thermal conductivity assumptions
    - Standard thermal conductivity models do not accurately account for small point contacts, small pore sizes with air, and radiative loss
    - Most accurate way to develop new highly insulating materials is to measure the thermal conductivities
  - **Evacuated capsules have substantially lower thermal conductivities than ones with air in them**
    - **Minimizing pores with air outside capsules and/or in disconnected pores should lead to insulation better than aerogels/fumed silica**
    - **Measurements indicate evacuated capsules may be more than 5 times better than aerogel insulation**
  - **Thermal models indicate 20% energy and cost saving achieved in U.S. with transparent vacuum insulation**
- Measurements
  - Measurements need improvement
    - While very reproducible, calibrations indicate Hot Disc needs more work, need to compare with Heat flow meter results
- Low cost manufacturing
  - **Demonstrated ability to synthesize vacuum capsules with uniform diameters of approximately 80 nm**
  - **Demonstrated ability to synthesize capsules with different geometries that have stacking densities close to 100%**
  - All materials and processes are scalable and low cost
    - Aqueous solution based sol-gel processes are used in large scale manufacturing of inexpensive products
- Transparency
  - **Demonstrated ability to disperse nanometer sized vacuum capsules to form completely transparent solution**
  - **Demonstrated ability to integrate vacuum capsules into transparent films that can be formed from microns to centimeters thick.**
  - Demonstrated initial assumption that the vacuum capsules should have similar optical properties to transparent aerogels and antireflection coatings
- Low-e coatings
  - Demonstrated thin films with commercial products like 3M's Prestige 90 to retrofit low-e films on installed windows
  - Could use broad band far IR reflector coatings deposited on vacuum capsules
  - Both cases will work, no issues with no air on one side or the other

Project Integration and Collaboration

Project Integration:

- Work with NREL's commercial, residential, emerging technology, and technology transfer buildings groups that have substantial experience and contacts within the buildings community including potential commercialization partners.
- **As project progressed and performance has been quantified, more industrial collaborators and partners have been engaged to help guide development and identify specific markets.**

Partners, Subcontractors, and Collaborators:

- Continued discussions and work with commercial companies to form key strategic manufacturing and market alliances.
    - **Coordinating follow-on project to develop manufacturing processes and products with company that makes vacuum capsules and IR-reflective films for windows**
        - Interested in developing manufacturing IP portfolio
    - Had detailed discussions with windows manufacturers about product performance requirements and potential integration strategies.
    - Specific partners will be identified once more formal arrangements and permissions have been obtained.
        - 3 NDA's executed so far

Communications:

- Future presentations at conferences, workshops, and review meetings are anticipated.

Next Steps

- Near-term (present project ends this year)
  - Continue efforts to demonstrate performance envelops on small samples (i.e., 1” to 6” diameter).
    - Balance transparency with thermal conductivity
  - Identify pathways to commercial processes
    - Inexpensive processes that can work in roll-to-roll ambient pressure system
- Longer-term (Follow-on Projects)
  - Work with commercialization partners
    - NDA’s executed with 3 companies
    - Develop commercialization plan
    - Develop manufacturing processes and products
    - Identify early market adopters
      - E.g., single pane window retrofits
        - » Lighter weight single pane windows with better insulation than triple pane. e.g., replacement glass for historic buildings or just lower cost windows.
      - Install in new windows and doors between double pain glass filled with Argon. Enables evacuation between plastic sheets that will not loose vacuum due to H2O infiltration.
      - Improve standard “foam” based insulation
      - Integrate with cloth or tenting materials
      - Main focus on low-cost manufacturing methods
    - Begin developing products.

NREL's Vacuum Insulation for Windows

Properties

- No air convection
- No conduction through evacuated part of capsules
- Conduction through capsule shell very small and determined by infinitely small contact areas
- Very small pore sizes with air in them has low conduction
  - Use smaller vacuum capsules
- Disconnected or closed pores with air will not affect TC
- IR radiation may be largest component of thermal conductivity
  - Use low-e coated films to decrease IR by 97%.
  - Can look at deposit films on vacuum capsules (e.g., TCOs)

Vacuum capsule advantages

- Degas more rapidly compared to aerogel or other small pore size insulation
  - Does not absorb as much water
- Has intrinsic structural properties
  - Can retain vacuum inside with no extra structures necessary
  - Accelerated tests show no leak, yet
- Well established chemistries
- Second best insulation found by NASA
  - More than 5 times better than aerogels/vacuum insulated panels
  - Applications just as insulator

Very transparent thin films

- Should be able to make thicker films very transparent too
- Transparent aerogels have optical properties similar to glass

Acknowledgements (Many People Providing Expertise)

- **Michele Olsen** and Phil Parilla: Thermal Conductivity Measurements
- **Chaiwat Engtrakul** and **Robert Tenent**: Coatings
- **Tim Snow** and Chaiwat Engtrakul: Durability and Reliability
- **Eric Bonnema:** Energy Performance Modeling and Cost Analysis
- **Eric Payne and Michael McIntyre**: Intellectual Property
- **Bill Hadley and Hudson Grigg** : Tech Transfer/Commercialization:
- **Bahman Habibzadeh, Karma Sawyer and Pat Phelan**: DOE Emerging Technology
- **Carrie Noonan, Craig Livorsi and L. Fabick**: DOE Golden Field Office

REFERENCE SLIDES

Project Budget

Project Budget: $375,000 in FY14 and $375,000 in FY15
Variances: NA
Cost to Date: ~$115,000 spent in FY15
Additional Funding: NA

Budget History					
FY2014 (past)		FY2015 (current)		FY2016 – Insert End Date (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$375,000	$0	$375,000	$0	NA	NA

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Project Plan and Schedule

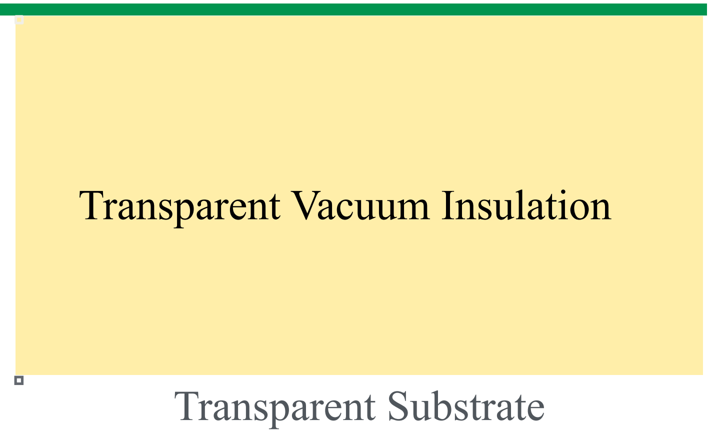
Project Schedule	
Project Start: October 1, 2014	Completed Work
Projected End: December 2015	Active Task (in progress work)
	Milestone/Deliverable (Originally Planned)
	Milestone/Deliverable (Actual)

	FY2015				FY2016				FY2017			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Current Work												
DQ4.1: PHASE I GO/NO-GO DECISION: Evacuated vacuum capsule has < 0.007 W/m-K thermal conductivity.												
MQ5.1 Down-select binder material/configuration for VI												
MQ6.1 Demonstrate transparent VI ...												
MQ6.2 Deliver first adoptor technology to market plan.												
MQ7.1 Thermal conductivity measured by company.												
MQ7.2 SMART: Demonstrate 4”x4” transparent VI												
Final FY 15 Milestone												
DQ8.1: Deliver VI with low-e for external testing												

BACK-UP SLIDES

Accomplishments: Initial Cost Model

- Model includes:
  - Nanomaterial synthesis
    - Cost of materials
      - Used commercial large volume prices
      - May be lower with vertical integration costs
    - Solution synthesis processes
      - Solution synthesis costs similar to commercial vacuum capsule prices
  - High temperature treatments and processes
  - Capital Equipment
  - Equipment labor
  - Equipment maintenance
  - Cost of capital
- Similar models vetted against PV Industry costs.



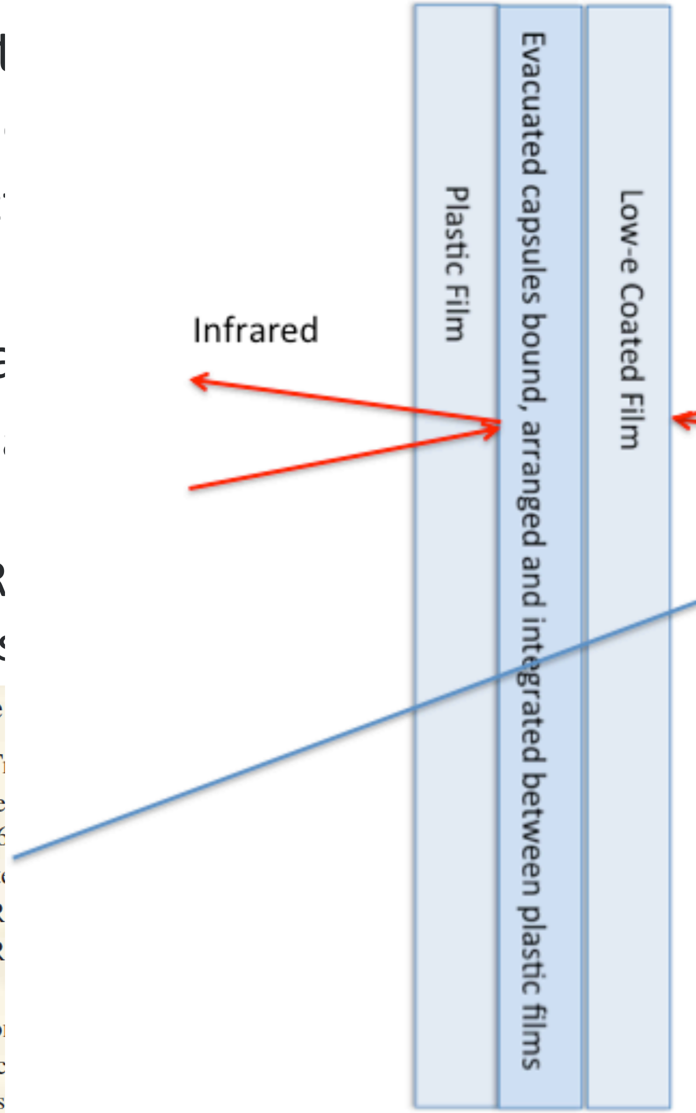
Assumes a 5 stage roll-to-roll slot coater system with heating operating at 45 m/ min.
Very low capital equipment costs.

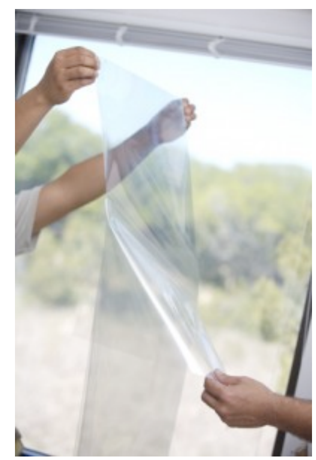
Progress: Decrease Radiative Transport

- Vacuum capsules integrated bet two sheets of plastic, one with l coated window films that reflec of IR radiative transport on the outside of NREL's vacuum insula
  - May be sufficient to minimize radi transport
  - If not, can integrate broad band IR reflective coatings on vacuum caps

Performance

Visible Light T
Total Solar Ene
TSER—On 6
Infrared Reject
Visible Light R
Visible Light R
UV Rejected
Glare Reductio
Luminous Effic
*Performance bas
IR rejection measured from 900-1000 nm





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Hot Disc Method

- Commercial system
- Provides rapid measurements of small samples
- Adaptable for measurements in vacuum

Picture of sensor head

- Homogeneous and heterogeneous
- Isotropic and anisotropic
- Solids, pastes and powders
- No thermal contact agent needed
- Direct measurement, no calibration required
- Two sided and single sided measurements

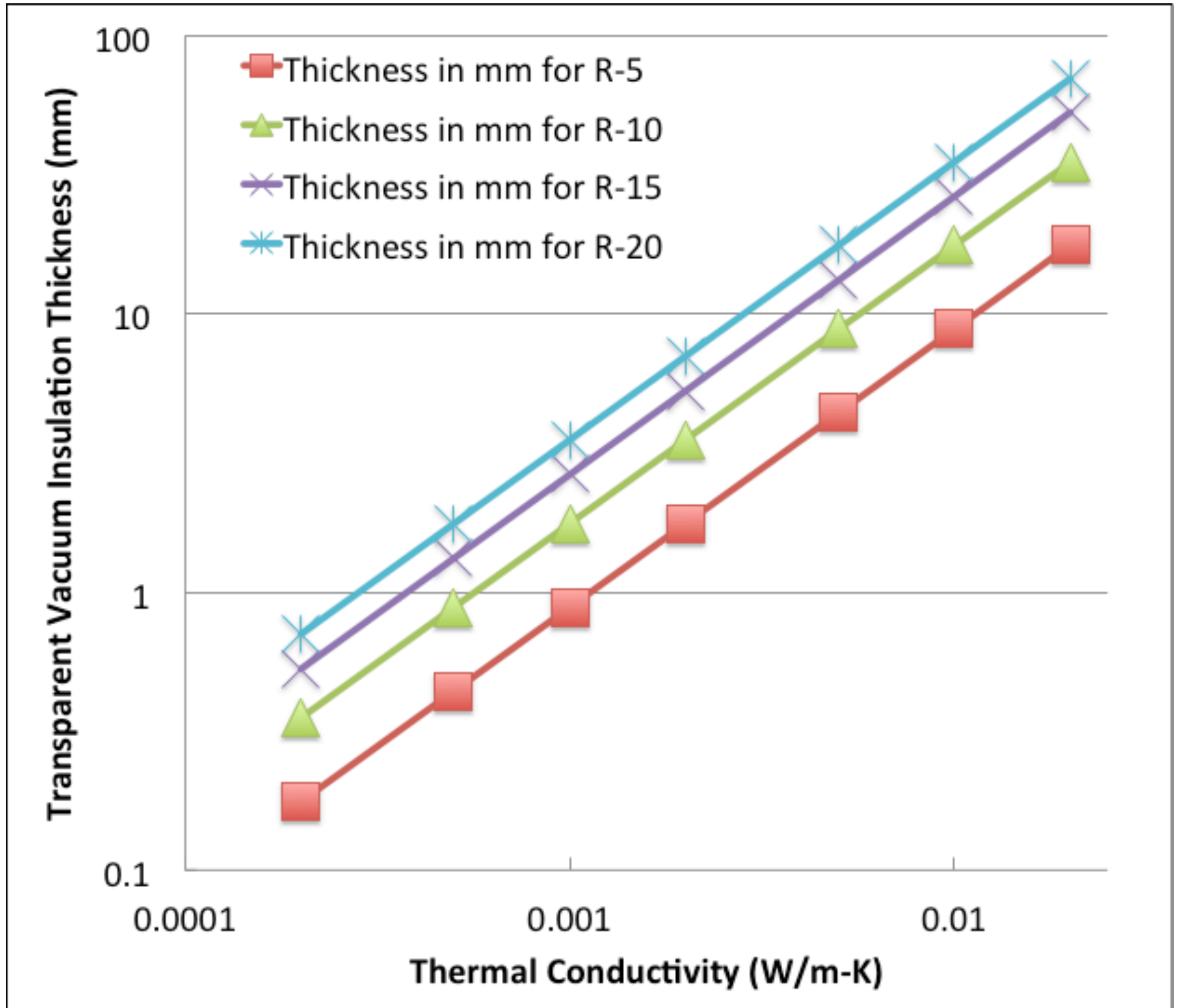
TPS 1500 SPECIFICATIONS*

Materials		Solids, Pastes, Powders
Orientation		Homogenous, Heterogeneous, Isotropic and Anisotropic
Applications		R&D, Polymers, Building Materials, Insulation, Bulk Solids
Measurement Capabilities		Bulk and Directional (Axial & Radial) Properties
Thermal Conductivity		0.001 to 20+ W/mK
Add. Thermal Properties		Thermal Diffusivity & Specific Heat
Measurement Time		20 to 1280 seconds
Reproducibility		Typically better than 1%
Accuracy		Better than 5%
Temperature Range	Temperature	Ambient (RT)
	With Furnace	RT to 300°C
	With Tube Furnace[1]	RT to 1000°C
	With Circulator[2]	-50°C to 280°C
	With Dewar[3]	As low as -160°C
Smallest Sample Dimensions		3 mm Thick, 10 mm Diameter or Square
Largest Sample Size		Unlimited
Sensor Types Available		Kapton insulated with or without cable (-160°C to 300°C)
		Mica insulated without cable (RT up to 1000°C)
Standard		ISO/DIS 22007-2.2

* Method is continually improved; specifications are subject to change without prior notice.
[1] Use of tube furnace requires vacuum / purged environment.
[2] Several optional circulators available based on size and temperature requirements
[3] Dewar apparatus is a manual set-point design

Conversion of Thermal Conductivity to R-Value

- Will need 2 to 20 mm of vacuum capsules



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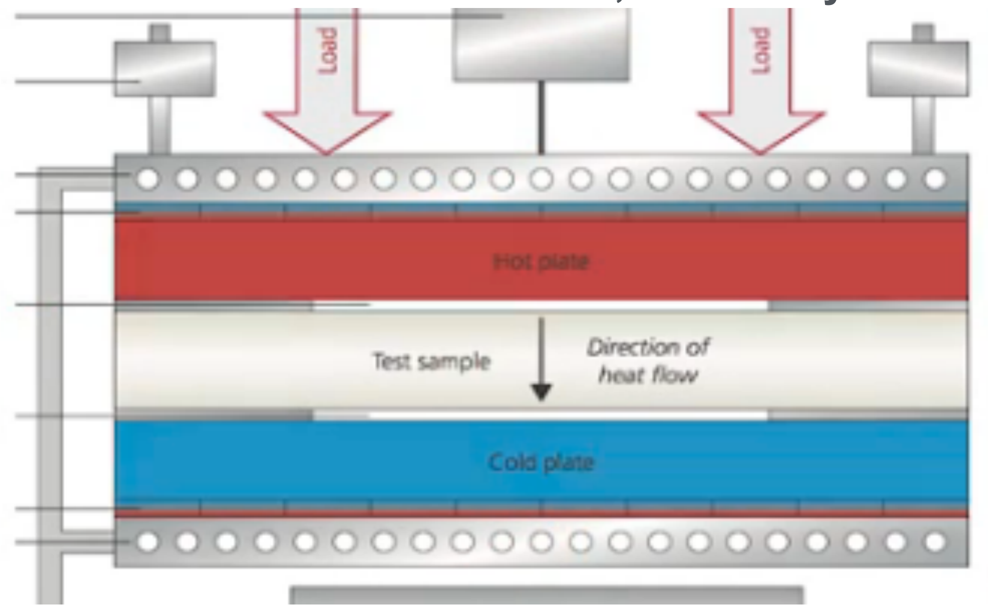
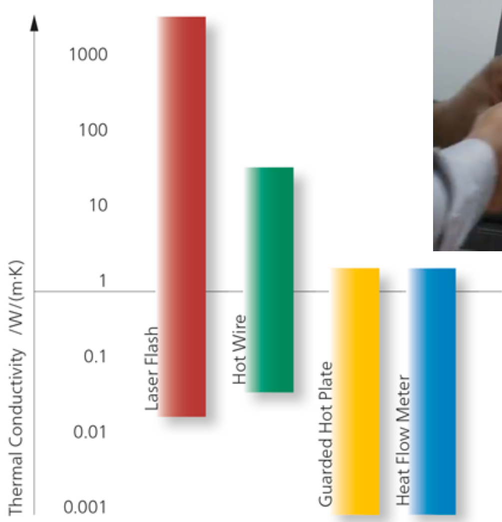
Highly Insulating Transparent Fenestration Testing

- Ultimately need to perform ASTM standards to compare VI with other products
  - ASTM Standard C1199 − 12 “Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods” on Transparent Vacuum Materials in system.
  - ASTM Standard ASTM C1363 – 11: “Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus”
  - May purchase commercial Hot Plate system to perform initial TC measurements
    - Main problem requires 30 cm X 30 cm x 1 cm sample sizes

Heat Flow Meter or Hot Plate, eventually NTS Differential Thermal Cycling Unit (DTCU)

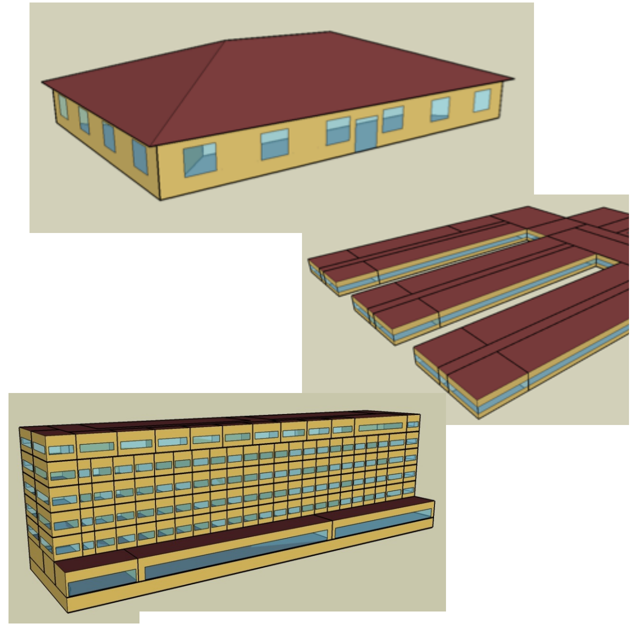


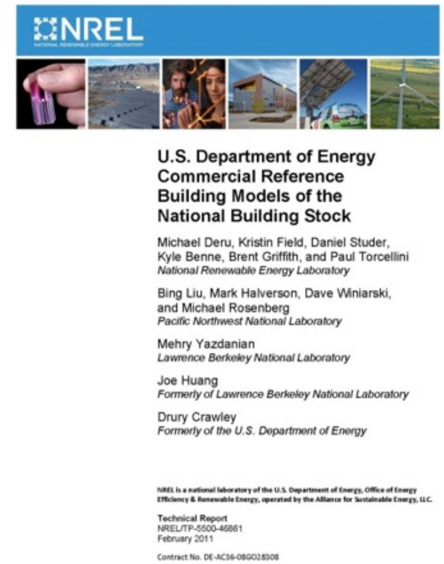


Progress and Accomplishments: Energy Savings Analysis

<u>Completed initial energy savings and cost per energy saved analyses</u>

- Apply technology to DOE commercial reference building energy models
  - Standard reference models provide a common set of inputs
- 16 building types and 16 locations
- Three sets of buildings
  - New construction – 90.1-2004
  - Post-1980 construction (~90.1-1989)
  - Pre-1980 construction (pre energy standards)
- Simulate models with and without technology in each location to provide savings potential values
- Apply factors that characterize the number of buildings that are similar to each reference building in each location to quantify impact potential

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U.S. Department of Energy Commercial Reference Building Models of the National Building Stock

Michael Deru, Kristin Field, Daniel Studer, Kyle Benne, Brent Griffith, and Paul Torcellini
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Bing Liu, Mark Halverson, Dave Winiarski, and Michael Rosenberg
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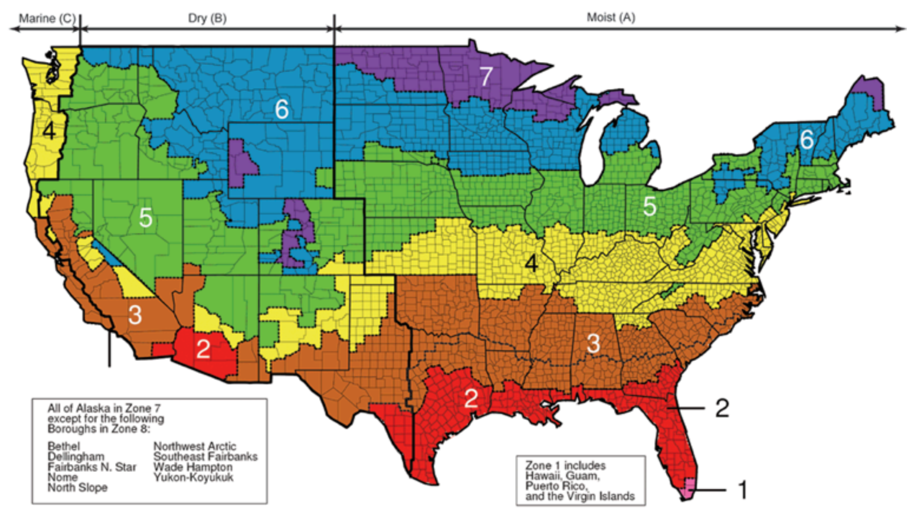

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Energy Model Details

Window Specifications: Assumed starting U-values of windows between 0.35 and 1.22, and added vacuum insulation with U-values between 0.2 and 0.025

Reference Buildings

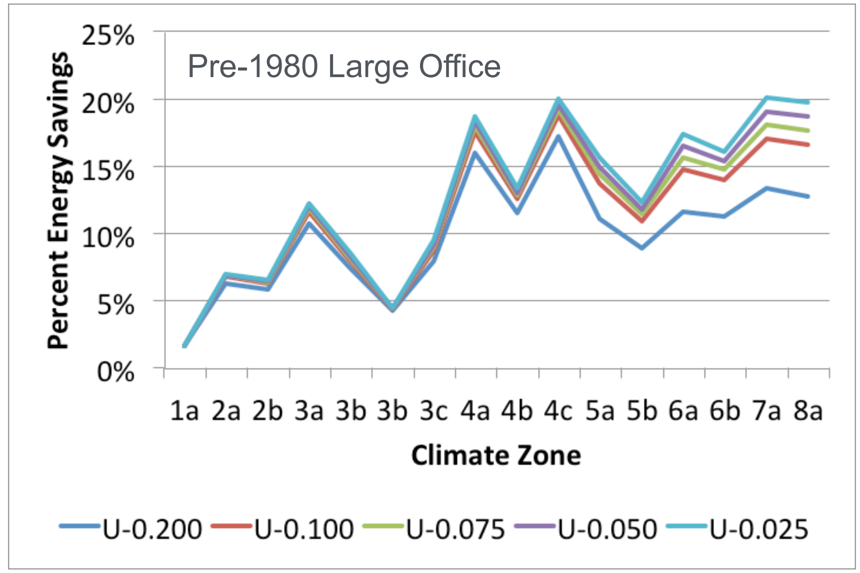
No.	Reference Building	Square Footage	Glazing Fraction
1	Full service restaurant	5,500 ft^2	0.17
2	Hospital	241,351 ft^2	0.15
3	Large hotel	122,120 ft^2	0.27
4	Large office	498,588 ft^2	0.38
5	Medium office	53,628 ft^2	0.33
6	Mid-rise apartment	33,740 ft^2	0.15
7	Outpatient healthcare	40,946 ft^2	0.19
8	Quick service restaurant	2,500 ft^2	0.14
9	Stand-alone retail	24,962 ft^2	0.07
10	Primary school	73,960 ft^2	0.35
11	Secondary school	210,887 ft^2	0.33
12	Supermarket	45,000 ft^2	0.11
13	Small hotel	43,200 ft^2	0.11
14	Small office	5,500 ft^2	0.21
15	Strip mall	22,500 ft^2	0.11
16	Warehouse	52,045 ft^2	0.006

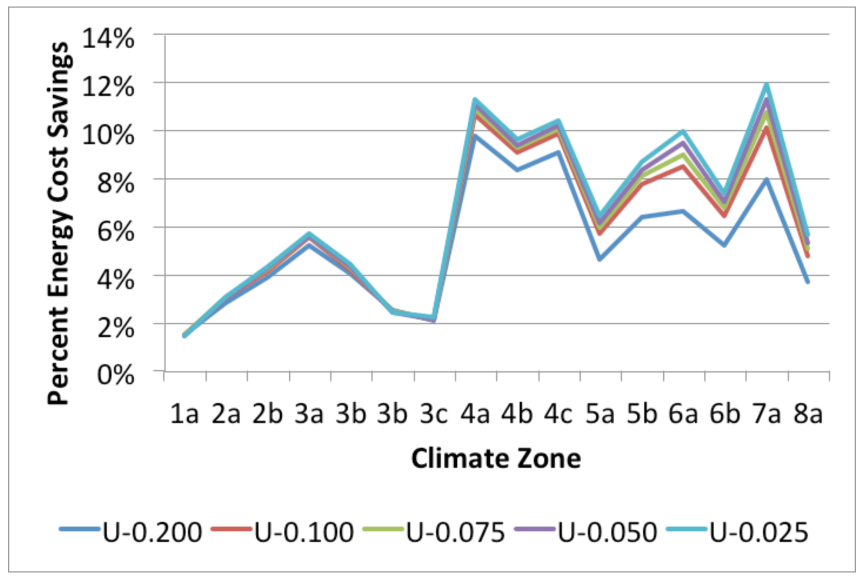
Climate Zones

No.	Climate Zone	Representative City	TMY2 Weather File Location
1	1A	Miami, FL	Miami, FL
2	2A	Houston, TX	Houston, TX
3	2B	Phoenix, AZ	Phoenix, AZ
4	3A	Atlanta, GA	Atlanta, GA
5	3B	Las Vegas, NV	Las Vegas, NV
6	3B:CA	Los Angeles, CA	Los Angeles, CA
7	3C	San Francisco, CA	San Francisco, CA
8	4A	Baltimore, MD	Baltimore, MD
9	4B	Albuquerque, NM	Albuquerque, NM
10	4C	Seattle, WA	Seattle, WA
11	5A	Chicago, IL	Chicago-O'Hare, IL
12	5B	Denver, CO	Boulder, CO
13	6A	Minneapolis, MN	Minneapolis, MN
14	6B	Helena, MT	Helena, MT
15	7	Duluth, MN	Duluth, MN
16	8	Fairbanks, AK	Fairbanks, AK

Accomplishment: Energy Modeling: Example of Results

- Average energy savings from baseline for all commercial building types in all environments is between 2.5% and 5% for U values between 0.2 and 0.025
  - These values even include “warehouse” structures with very few windows.
- However, even U-0.2 can save ~19% for some buildings in some climates.
  - This increases to ~23% for U-0.025
- These energy savings translate to as much as 12% reductions in costs.
- Benefits approximately the same on inside or outside of window





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