Field Demonstration of Superior Performance of Advanced Building Envelope Technologies

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Agenda

- Introduction
- Objective
- Field Experiments
- Results
- Summary and Conclusions

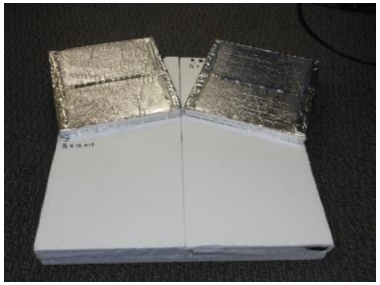
Building Thermal Insulation

- Space heating and cooling requirement in the U.S.
  - ~13 quads of primary energy consumption each year
  - $142 billion in energy expenditure
- Thermal insulation is a simple and straightforward way to retard the heat flow across the envelope and save on energy
- Issues with conventional building insulations (fiber-based and plastic foam)
  - Limited thermal performance (max. R-7 per inch)
  - Poor fire performance
  - Fire retardant additives are potential health hazard – potential carcinogen and produce toxic fumes which may cause developmental and neurological disorders

http://buildingsdatabook.eren.doe.gov/

Emerging Building Envelope Technologies

- Vacuum Insulation Panels (VIP) and Aerogel are high performance insulations
  - R-35 per inch (k ~0.004 W/m-K) for VIP
  - R-10 per inch (k ~0.014 W/m-K) for Aerogel
  - Inherently nonflammable
  - Great potential in high-R building enclosures and deep energy retrofits
- Phase Change Material (PCM) relies on latent heat storage and release
  - Not an insulation
  - Used to regulate interior space temperature and peak load shifting



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Challenges

- Adoption of these technologies has been slow in the U.S. building market
  - Relatively high price compared to conventional insulations
  - Price and performance have improved in recent years
  - Cost-effective in high-R building enclosures and deep energy retrofits
- Field deployment and performance validation is needed to
  - Advance the understanding of these technologies in real-world conditions
  - Gain greater confidence in the technology
  - Needed to validate whole-building energy models

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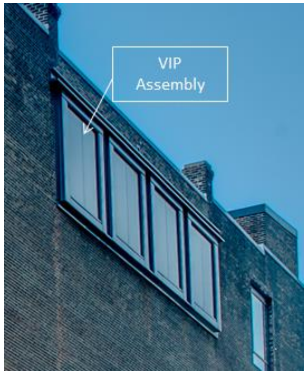
Objective

- Deploy Aerogel, PCM and VIP technologies in the envelope of building-scale structures exposed to outdoor conditions, and generate real-world thermal and energy performance data

Strategy

- Two separate demonstrations
  - Aerogel and PCM in building-scale test hut structures located in Albuquerque, NM outdoor test facility
  - VIP on the south-facing façade wall of Fh Living Laboratory building in Boston, MA
- Measure temperature and heat flux through the appropriate envelope elements
- Evaluate the thermal and energy performance



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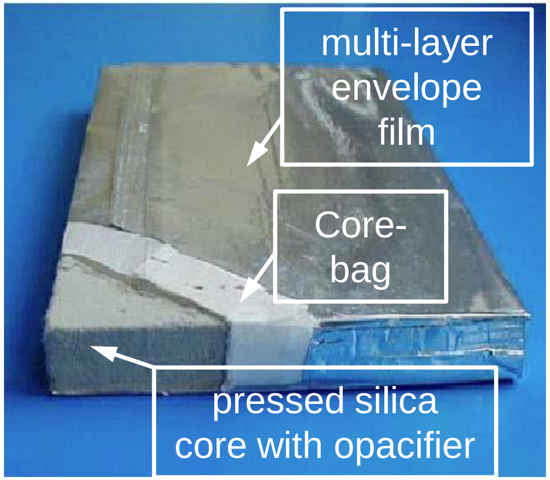
Vacuum Insulation Panel (VIP)



- A VIP consists of a nanoporous core that is evacuated and enclosed in a container that is highly impervious to air and water vapor transmission
- Thermal conductivity as low as 0.004 W/m-K

http://www.ecbcs.org/docs/Annex_39_Report_Subtask-A.pdf

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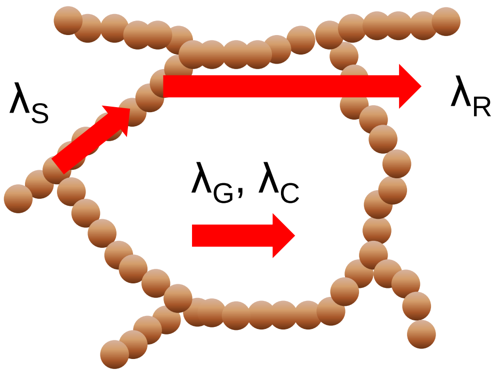
Aerogel

- Aerogel is a gel whose liquid component is completely removed and replaced with air
- High porosity (90%-99.8%) and nanoscale pore size (10-100 nm) give rise to unique and extreme properties
- As building insulation – ultra-low thermal conductivity, light weight, fire resistant, water repellent and non-toxic

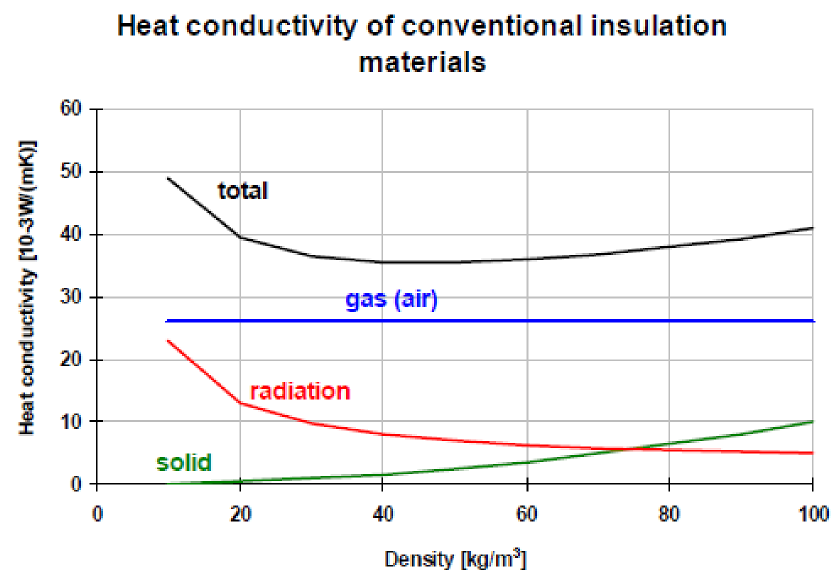
https://eetd.lbl.gov/newsletter/cbs_nl/nl08/cbs-nl8-aerogel.html

Heat Transport in Conventional Insulations



$$\lambda_{total} = \lambda_{solid} + \lambda_{gas} + \lambda_{convection} + \lambda_{radiation}$$

- Mineral fiber and polymeric foams
- Microporous media at atmospheric pressure: ~10-100 um pore size
- Porous structure implies only limited number of channel for heat conduction
- Gas conduction dominates the thermal conductivity



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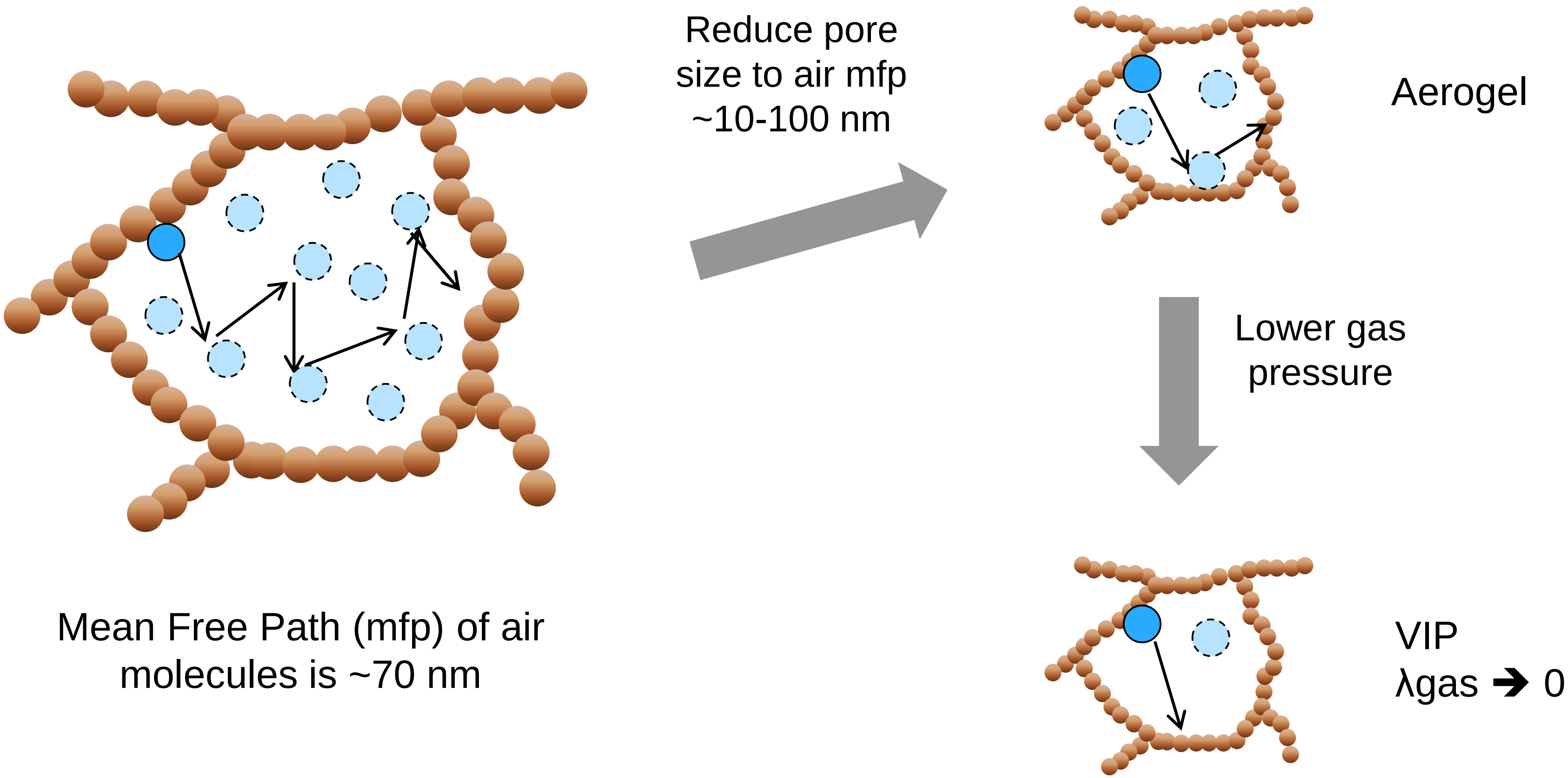
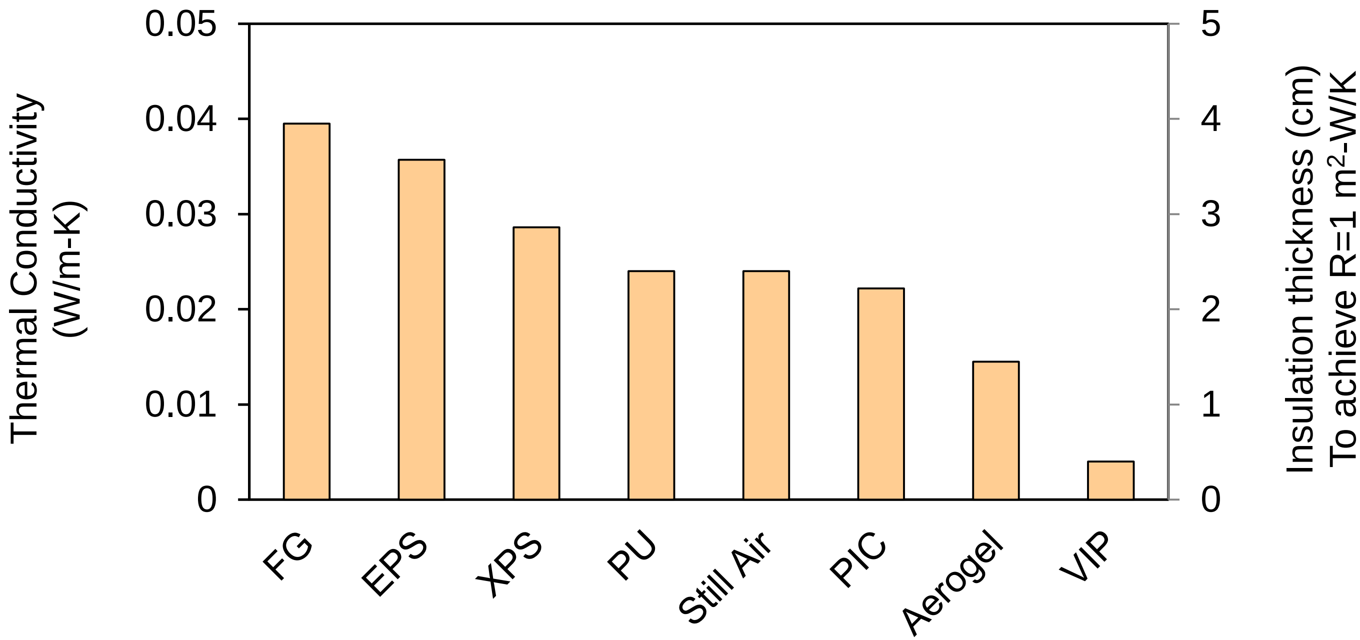
Heat Transport in VIP and Aerogel



Superior Thermal Performance



- VIP and Aerogel offer one of the highest thermal resistances of any insulation technology
- Thinner solutions for a given target thermal resistance

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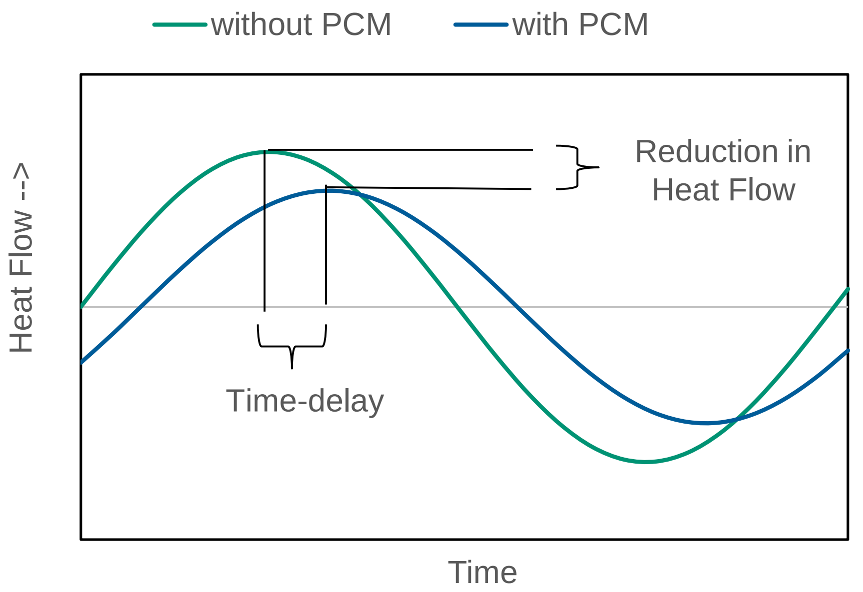
Phase Change Material (PCM)

- PCM is a material that absorbs or releases a large amount of heat as it melts or freezes, respectively (i.e. material with high heat of fusion)



- When applied in the building envelope, PCM may help regulate the interior temperature by storing the excess heat during the daytime and releasing it during cooler night time as it freezes
- PCM also causes a time delay in the peak heat flows, a feature very attractive in regions with double electricity tariff

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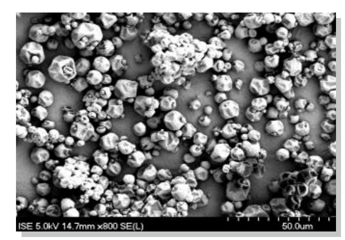
Phase Change Material (PCM)

- Two types of PCM
  - Organic – paraffin
    - 👍 easy encapsulation, relatively low-corrosivity
    - 👎 flammable, expensive, leakage
  - Inorganic – salt hydrates
    - 👍 inexpensive, higher volumetric heat storage, non-flammable
    - 👎 challenging containment, super-cooling
- Significant advances during the last decade
  - Shape-stabilization
  - Bio-based PCM – cost have dropped to $3-5/lb
    ➔ Potential payback ~5-7 years
  - Microencapsulation of inorganic salt hydrates





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Field Experiments

1. Aerogel and PCM Demonstration

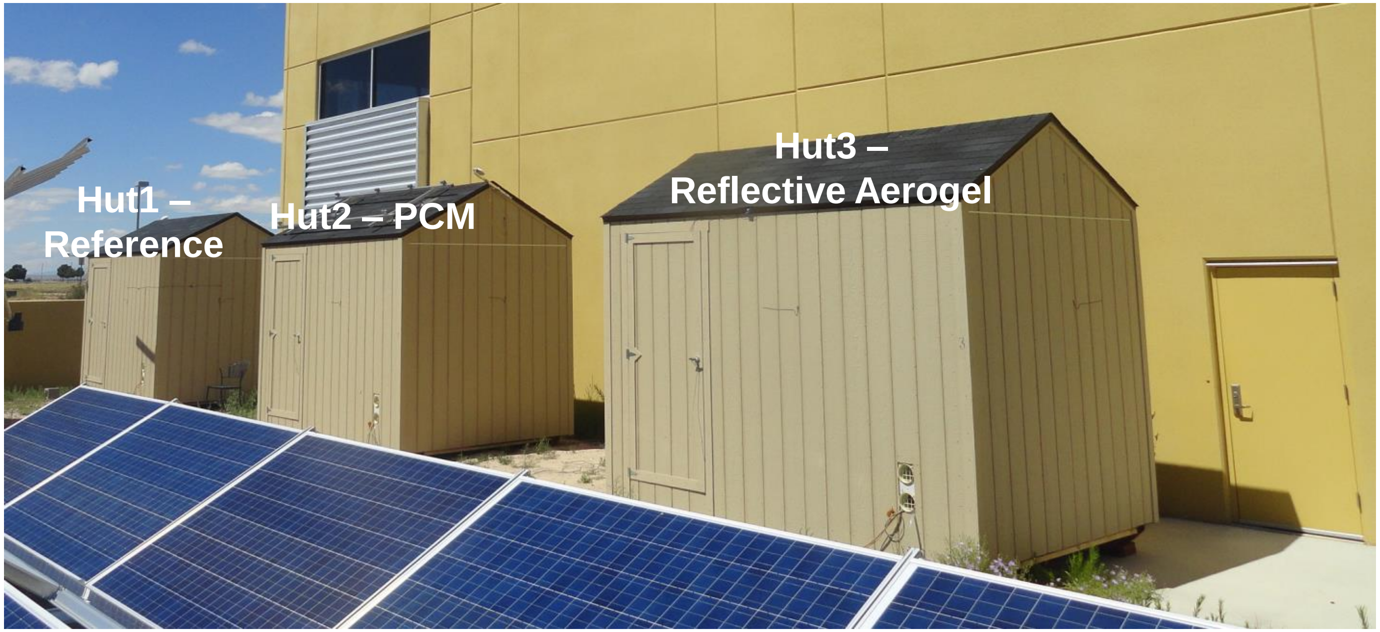
- Three identical test hut structures – 8’x12’ footprint, A-frame, ~9.5’ tall, standard wood-frame construction
  - Hut 1 – Served as the reference
  - Hut 2 – Aerogel blanket (1 cm thick) installed below the roof deck cavity and behind the gable cavity. Aerogel blanket was 1 cm thick with R-4 $hr.ft^2.^oF/BTU$ and contained reflective Aluminum facing on both sides.
  - Hut 3 – A form-stabilized PCM sheet installed across two layers of OSB ceiling. 0.5 mm thick with a total heat storage of 120 kJ/kg in the phase active range of 20^oC to 30^oC with peak melting of ~25^oC.
- Ceiling separated conditioned space from the unconditioned attic space.
- Each test hut was instrumented with sensors (thermocouples, heat flow transducers, RH meters)
- Interior space temperature was maintained at 21^oC using a portable air conditioner.
- The test was conducted during summer time between 06/01/2014 and 09/08/2014.

Aerogel and PCM Demonstration

Test Structure	Walls	Roof	Gables	Ceiling (Top to Bottom Layers)
Hut 1 (Reference)	R-13 FG batt in cavity + 50 mm (2 in.) XPS	None	None	50 mm (2 in.) XPS + 11 mm (7/16 in.) OSB
Hut 2 (PCM)	R-13 FG batt in cavity + 50 mm (2 in.) XPS	None	None	25 mm (1 in.) XPS + 5 mm (0.2 in.) PCM + 25 mm (1 in.) XPS + 11 mm (7/16 in.) OSB
Hut 3 (Aerogel)	R-13 FG batt in cavity + 50 mm (2 in.) XPS	10 mm (3/8 in.) Reflective Aerogel	10 mm (3/8 in.) Reflective Aerogel	50 mm (2 in.) XPS + 11 mm (7/16 in.) OSB

PCM Sheet

As-constructed Test Huts



As-constructed Test Huts

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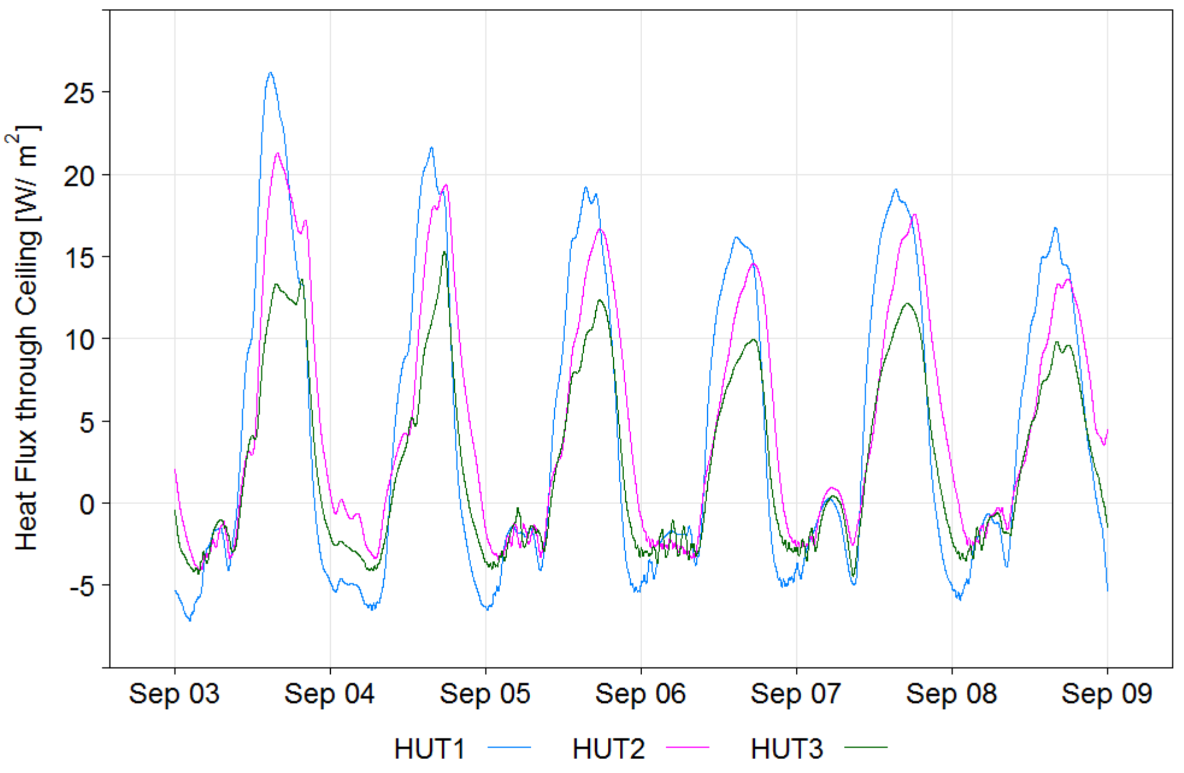
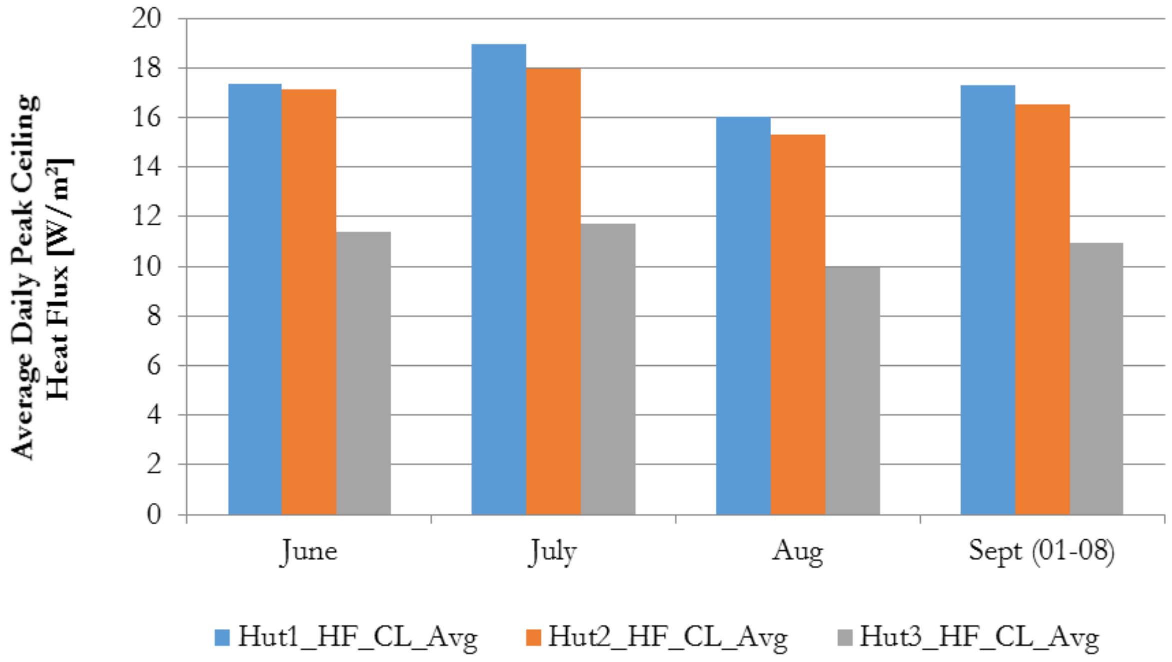
Ceiling Heat Flux



- Reflective Aerogel test hut shows the lowest peak heat flux

Monthly Average Daily Peak Heat Flux



- MACHF: Reference Hut > PCM Hut > Reflective Aerogel Hut

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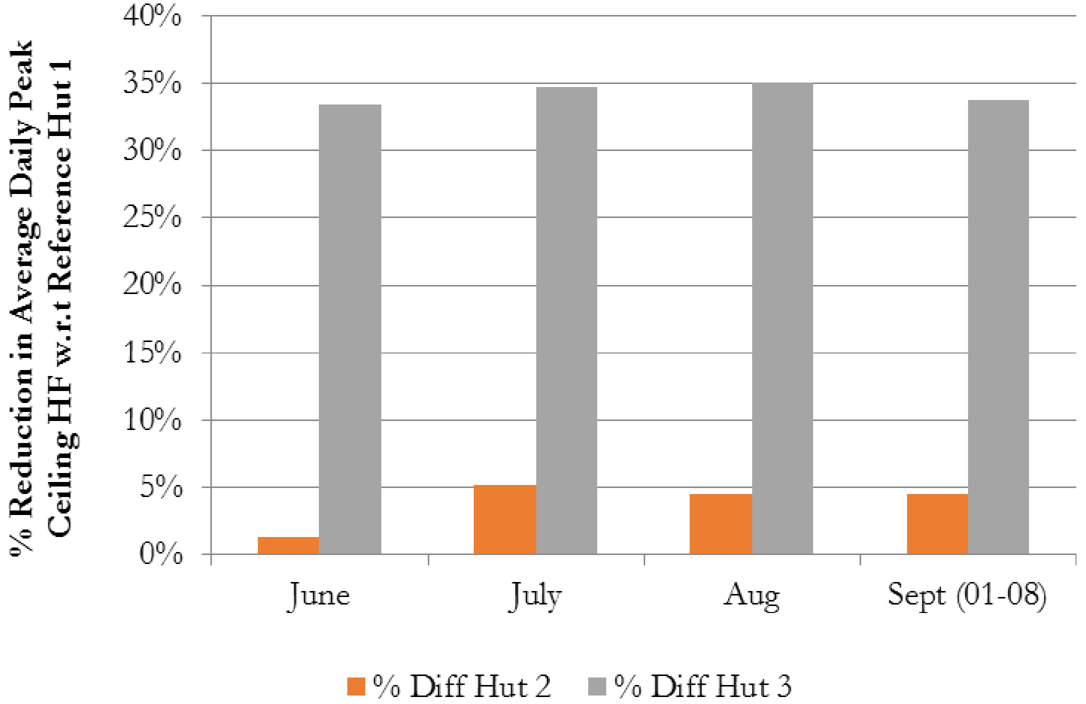
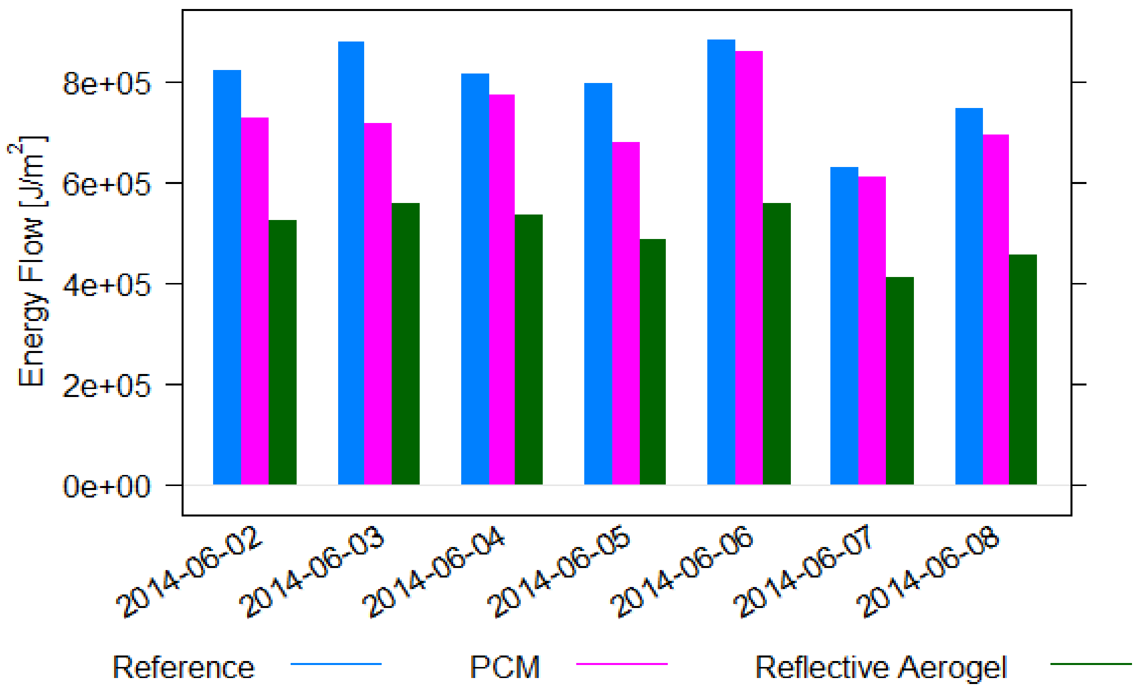
Monthly Average Daily Peak Heat Flux



- PCM in the ceiling caused a small reduction (2%-5%) in MACHF
- Reflective aerogel in roof deck and gable caused a significant reduction (33%-35%) in MACHF

Attic-generated Daily Cooling Load



- For the test duration: Reference Hut (56.6 MJ/m^2) > PCM Hut (55.2 MJ/m^2) > Reflective Aerogel Hut (34.9 MJ/m^2)
- PCM and Reflective Aerogel technologies as deployed save ~2.5% and 38%, respectively, of the attic-generated cooling loads compared to the Reference

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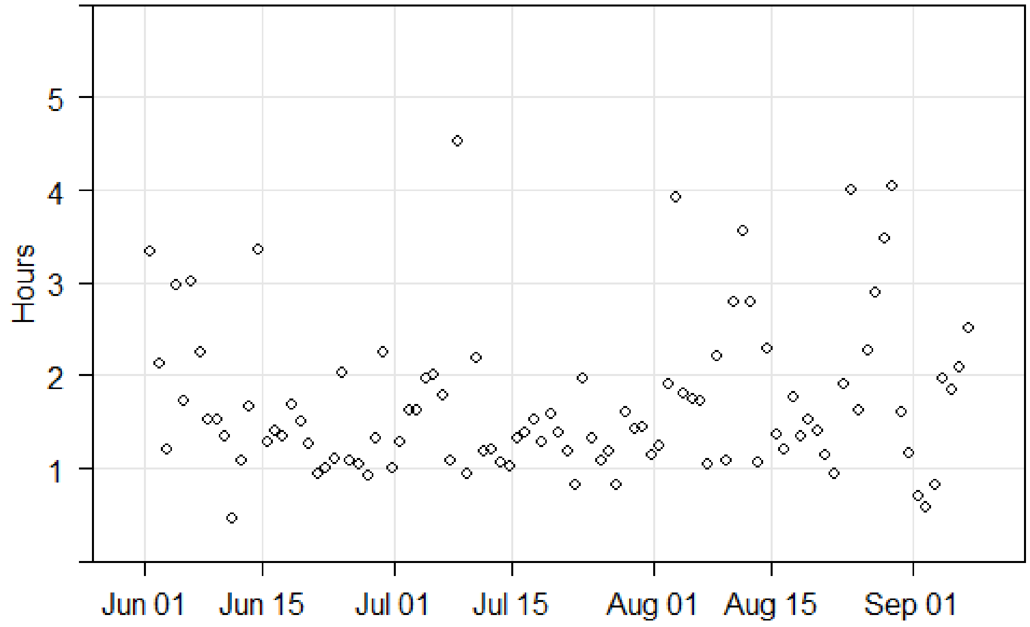
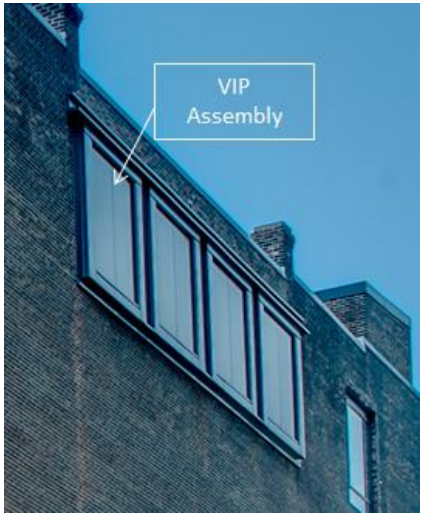
Time-shift in Daily Peak Heat Flux

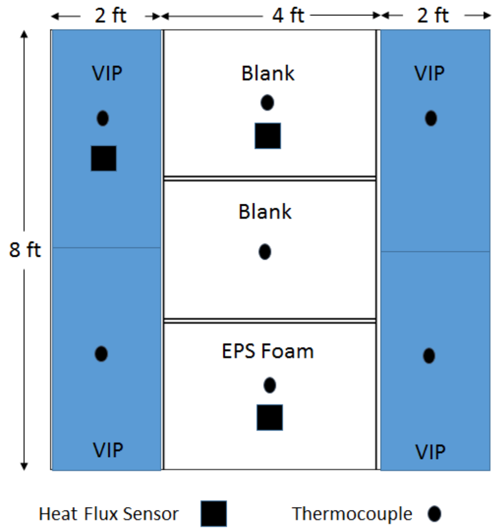


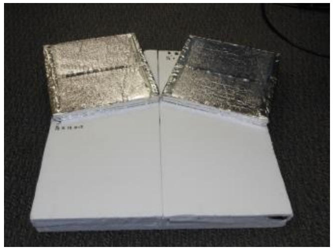
- Presence of PCM in the ceiling effects a time-shift in the occurrence of the daily peak heat flux
- Time-shifts as large as 4.5 hour was observed
- An average time-shift of 1.68 hour (101 minutes)

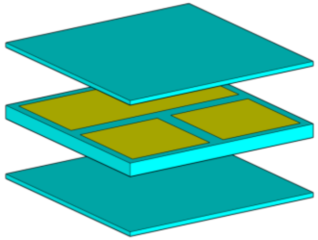
2. VIP Demonstration

- Façade Panel Testing Platform consists of a series of 2’ wide wall plugs constructed using 1” thick insulated metal panel to support the building envelope material to be tested
- 3” thick VIP assembly and 3” thick EPS were installed from inside over the wall plugs
- VIP Assembly consisted of a 1” thick VIP sandwiched between layers of 1” thick XPS to protect against mechanical damage and for easy handling
- Experiments were conducted during 3 weeks of summer (08/01/2014–08/21/2014)









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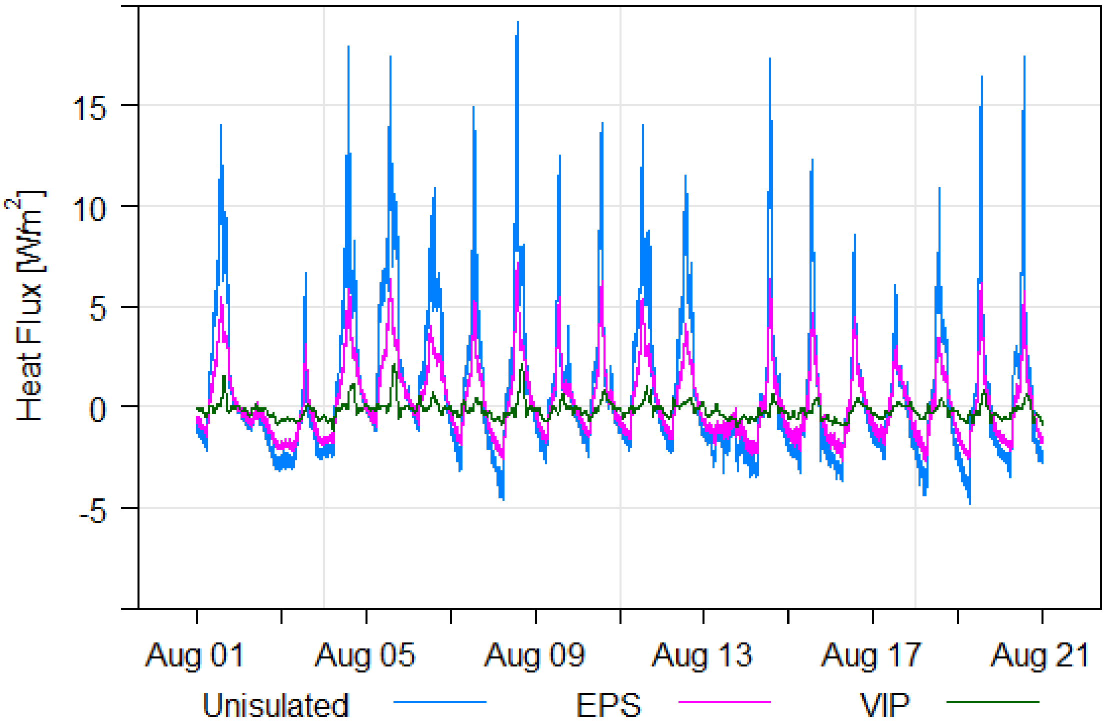
Heat Flux



- Almost negligible heat flow to through the VIP wall assembly!
- EPS wall section shows 30%-40% reduction in peak heat flux

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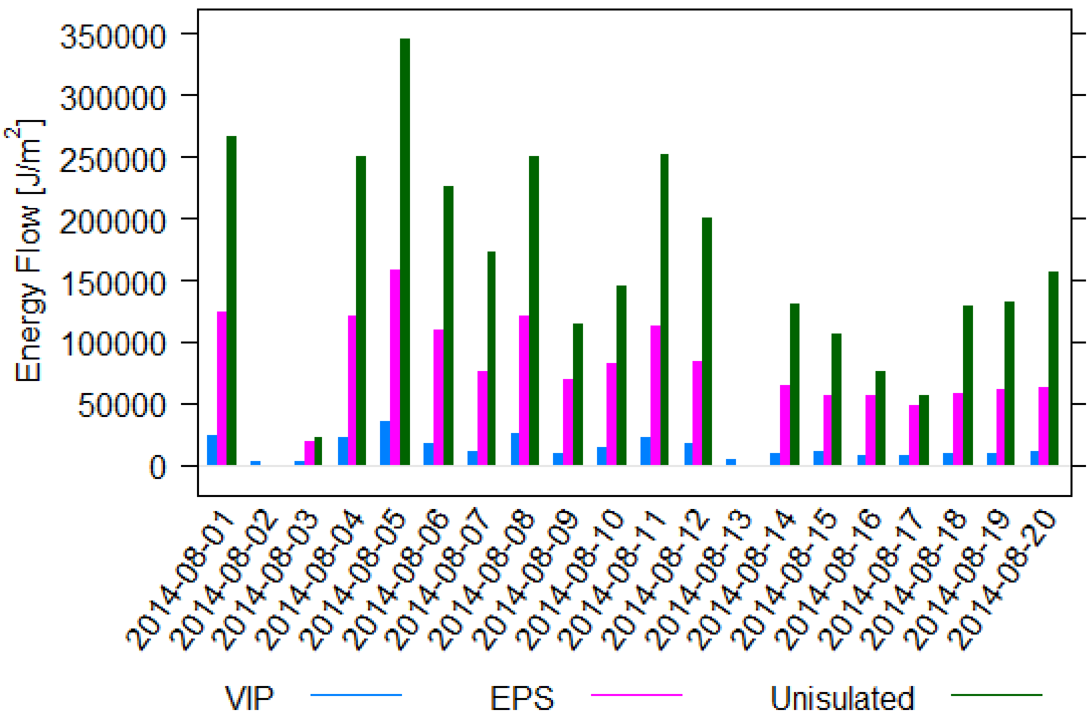
Cooling Demand through Wall



- Daily cooling load reduction in the range of 90%-95% and 50%-60% in VIP and EPS wall sections, respectively, compared to the reference wall
- VIP section generates approx. 82% less cooling load than the similar thickness EPS section

Summary and Conclusions

- VIP, Aerogel and PCM are emerging energy saving building envelope technologies
- Aerogel and PCM were deployed in building-scale test huts and VIP in wall assembly to learn about their field performance and generate computer validation data
- Addition of 1 cm thick Reflective aerogel in roof deck and gable reduced the monthly daily peak heat flux and ceiling-generated cooling demand by 33-35% and 38%, respectively, during the summer months
- Introduction of PCM layer in the ceiling structure shifted the daily peak heat flow by an average of 1.68 hour, a feature attractive in locations with double electricity tariff
- 7.5 cm thick VIP assembly performs 82% better than a similar thickness EPS-insulated wall assembly, during the summer testing period

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Thank You!