

Innovative materials to address building challenges in the face of climate change



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Metropolitan
University**



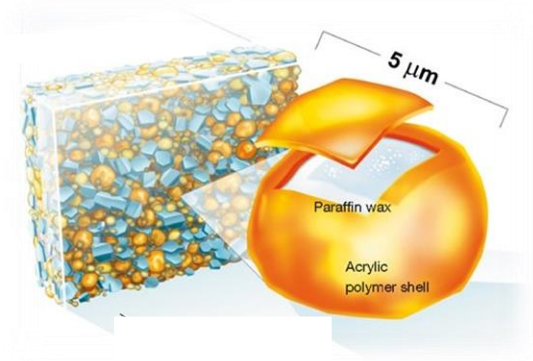
BeTOP (Building efficiency: Testing, Operation and Performance)



City of Toronto, 2015

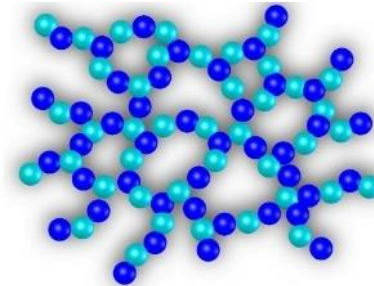
Outline: disruptive innovations in material science

1. Phase Change Materials (LHTES)



2. Aerogel-enhanced systems

3. Innovative Foams and geopolymers



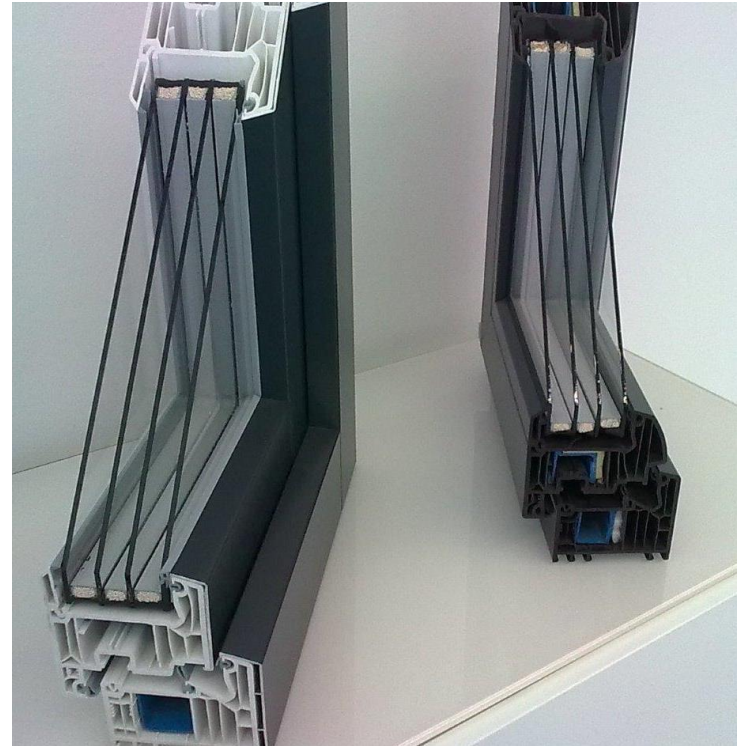
4. Retro-reflective materials

5. Climate-sensitive materials

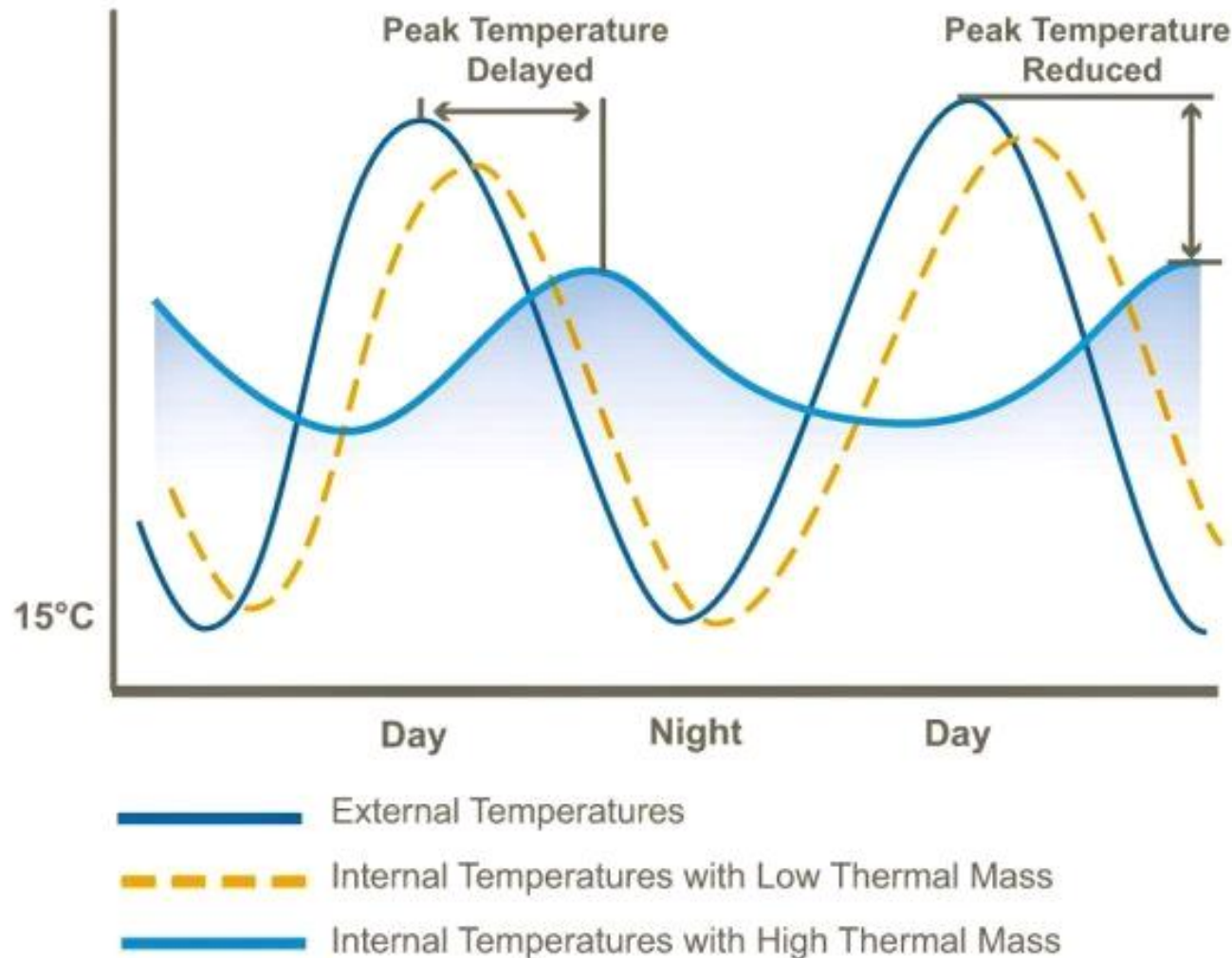


The scope of a building is occupants' comfort

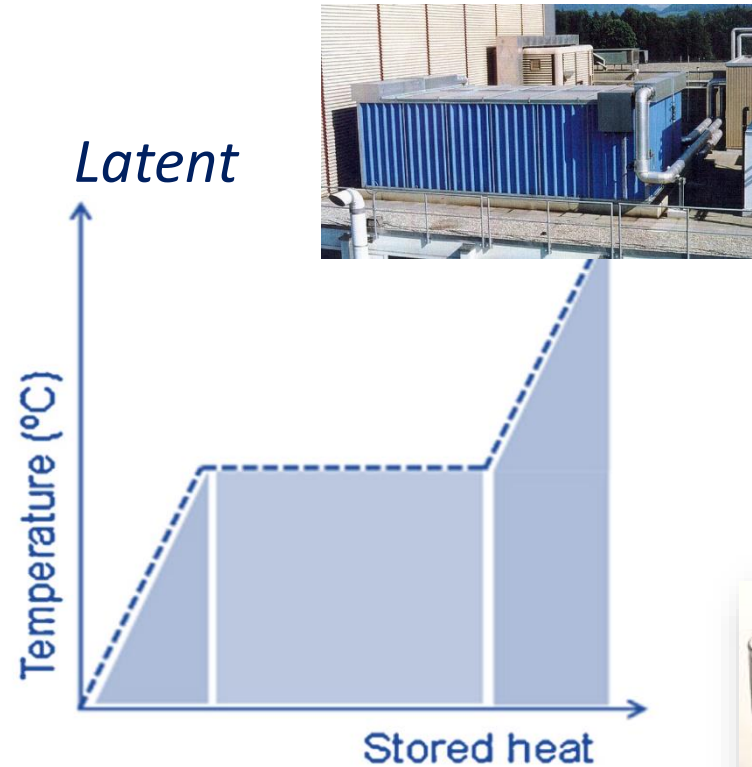
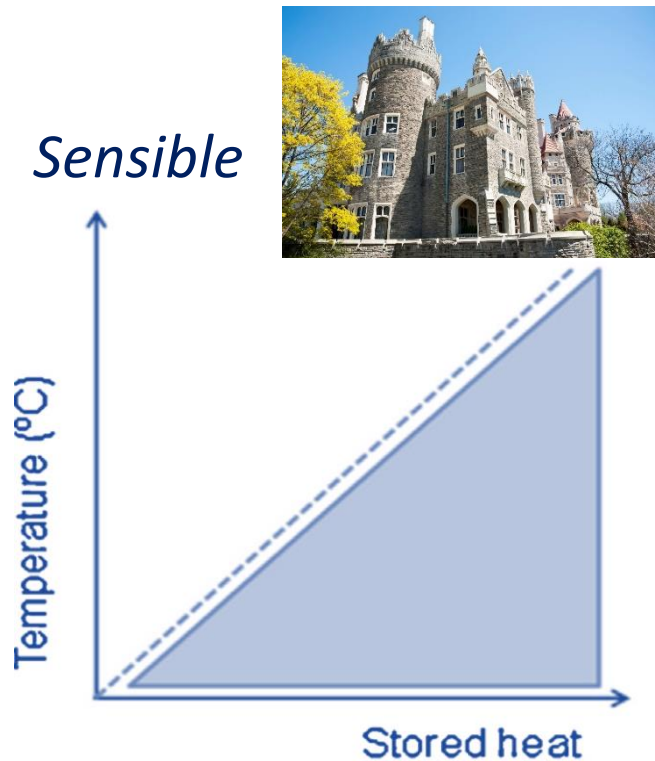
.. but the requests of *Building Codes* often limit to *R-value* ..



Thermal Mass *and thermal storage* are coming back



Thermal Energy Storage (TES)



For example: the sensible heat capacity of water is **4.2 J/gK**, whereas its latent heat capacity is **334 J/g** in case of solidification



Recent contributions about TES with PCM

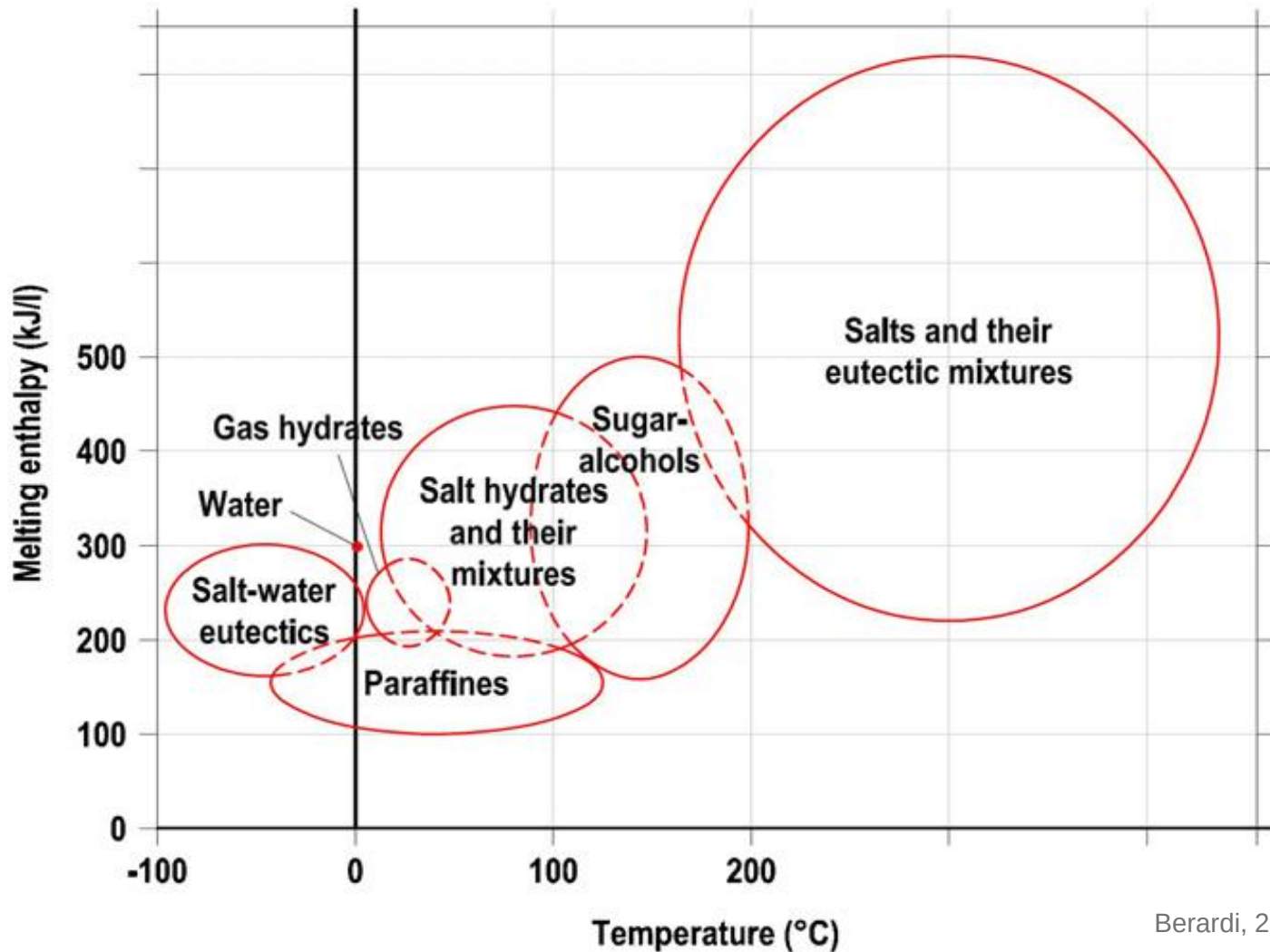
Research is focusing on both new laboratory studies and real building projects.

This because the boundary conditions of lab studies often misrepresent the conditions in real buildings:

- Selecting the right PCM
- Research in innovating PCM
- Real effectiveness of TES



PCM selection

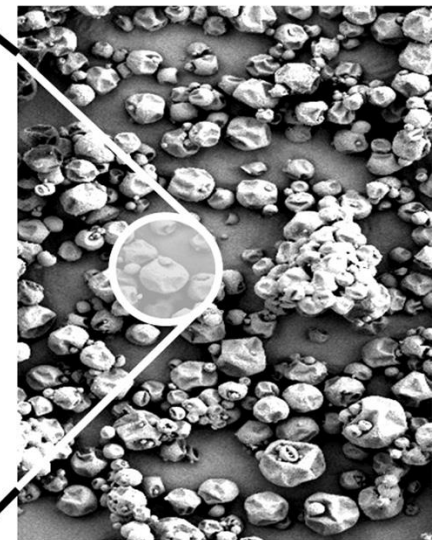
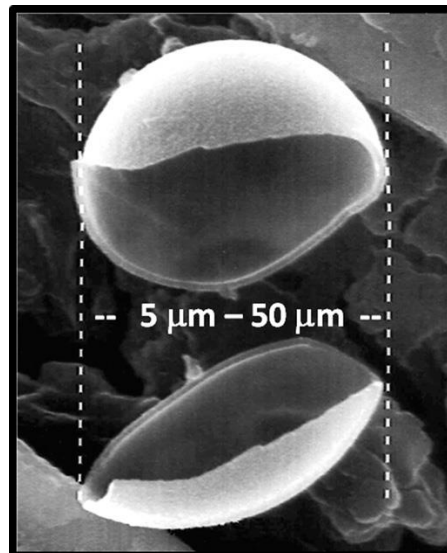


Berardi, 2019

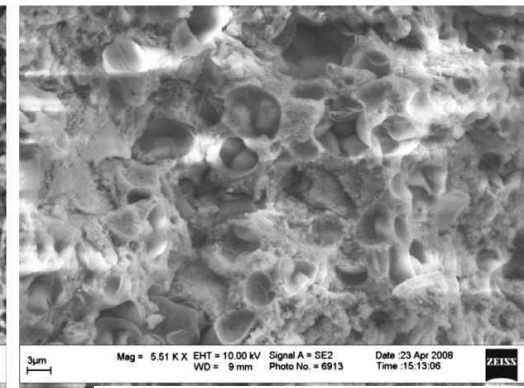
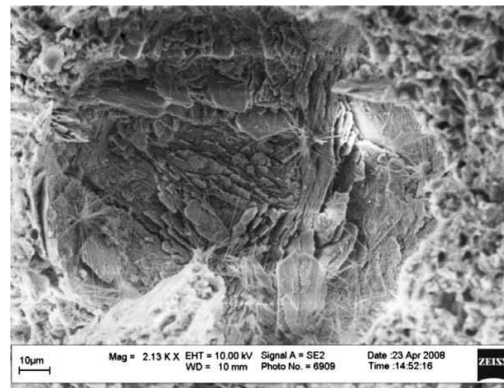
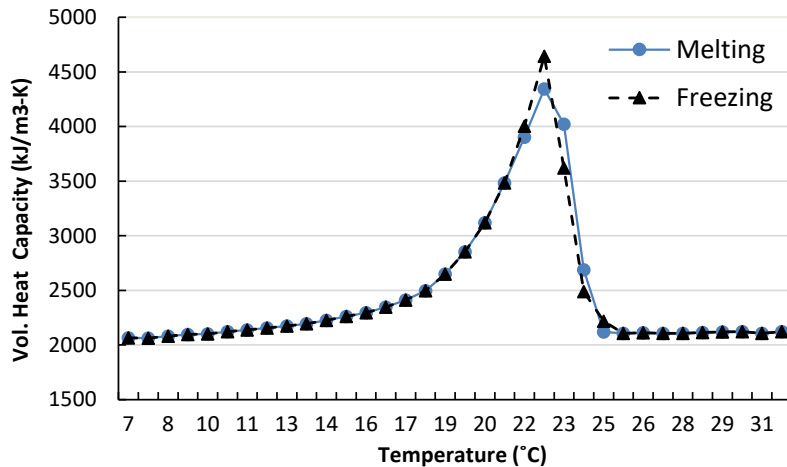
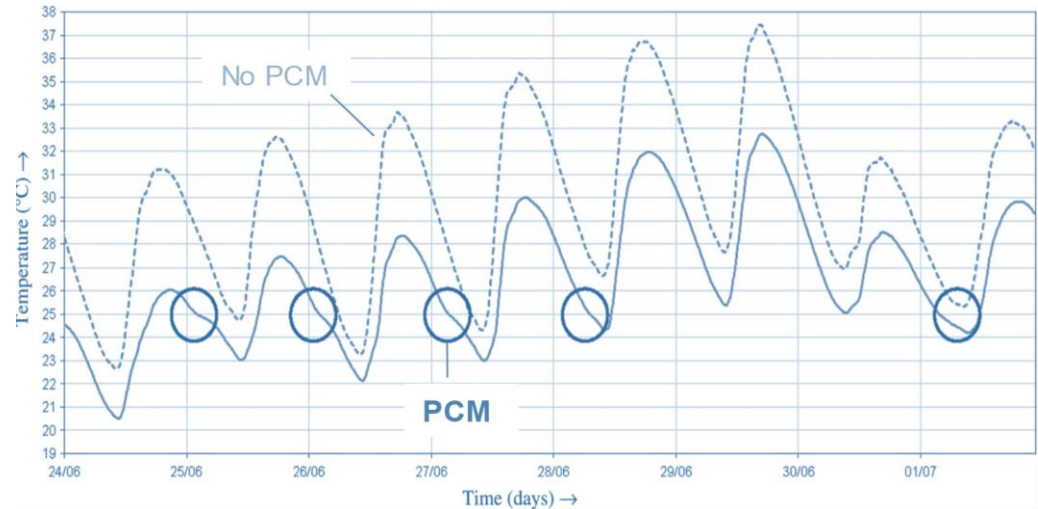
PCM in buildings: the (micro-)encapsulation

Encapsulation is a key issue for the implementation of PCMs in buildings and it serves to avoid leakages and corrosion.

PCM can be incorporated in construction materials using different methods, such as direct incorporation or immersion.

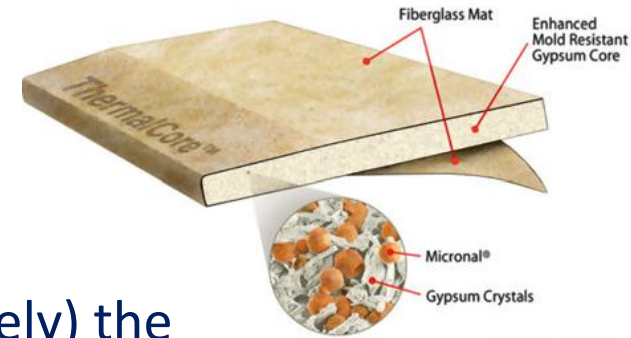


PCM-enhanced concrete systems

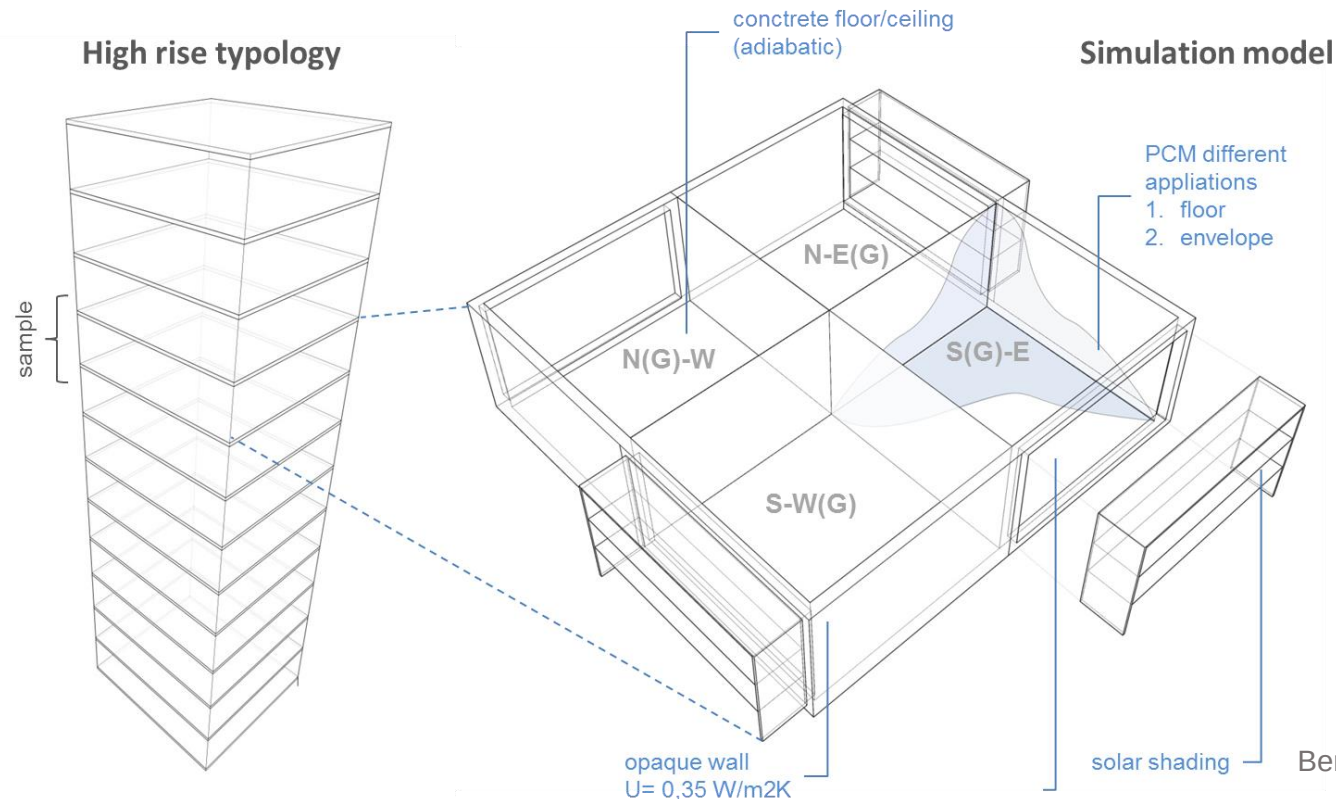


Berardi et al., 2015, 2018, 2019

TES in high-rise buildings



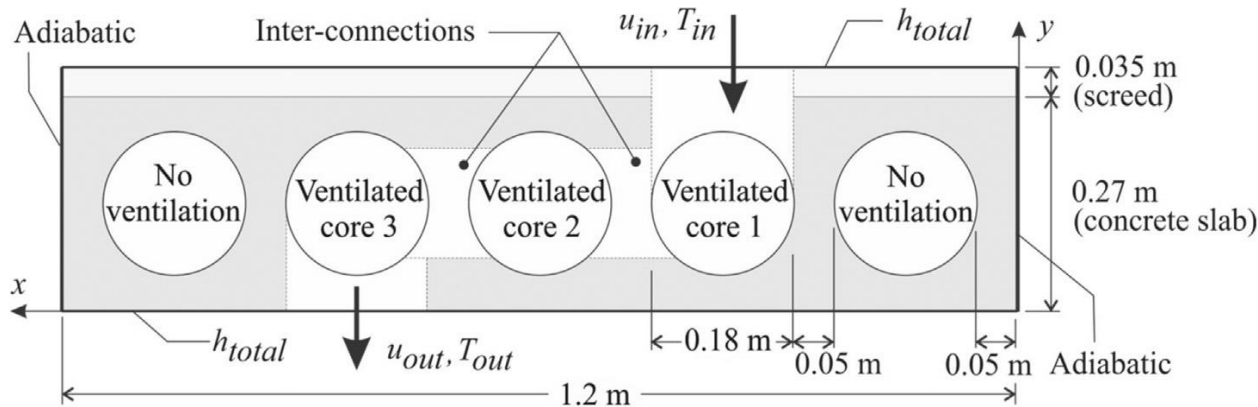
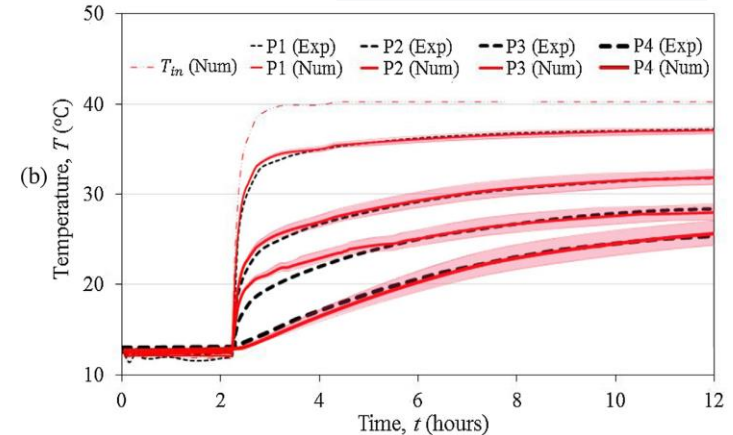
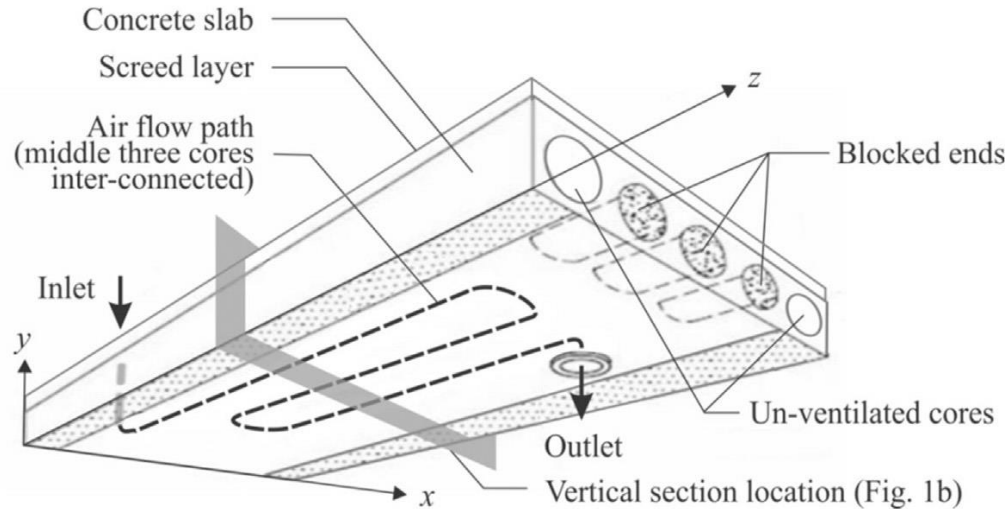
PCM wallboards have shown to decrease (passively) the temperature fluctuations in Toronto glass towers by almost 6°C, with cooling energy demand reduction of 15%.



Berardi and Manca, 2017

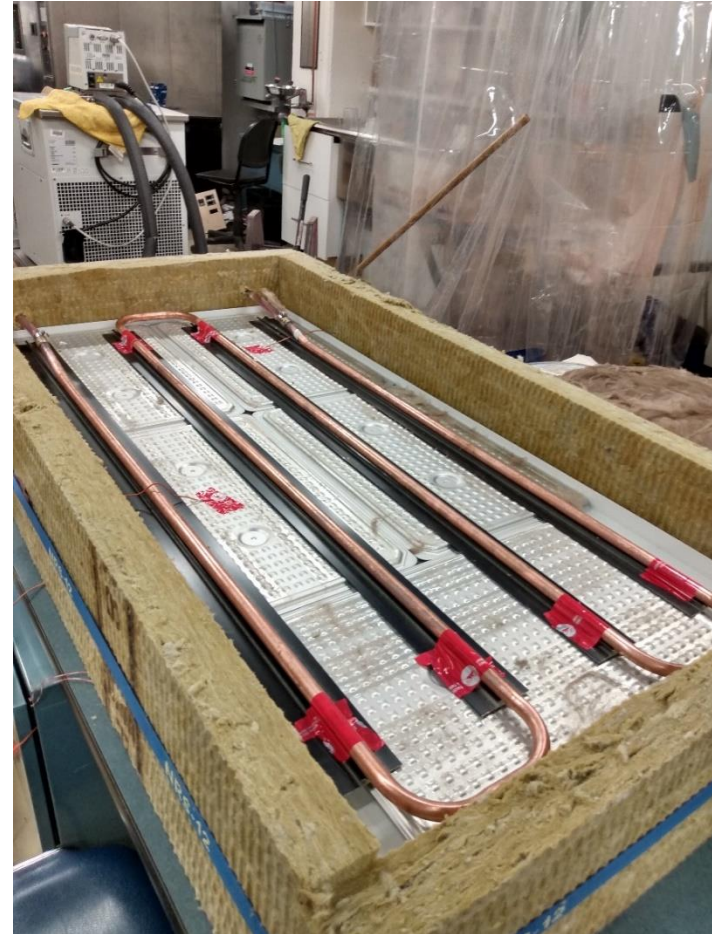
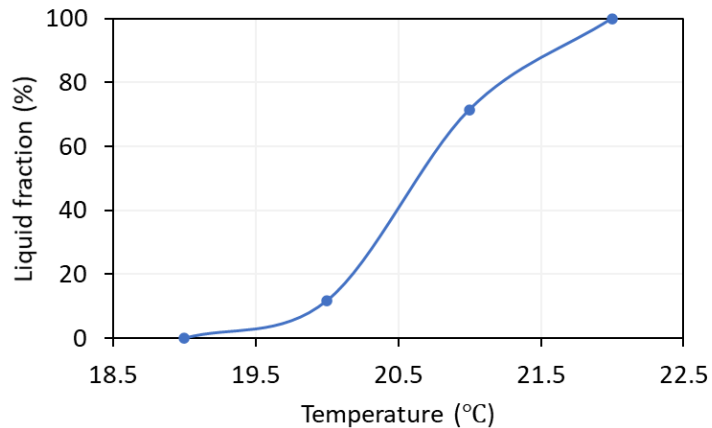
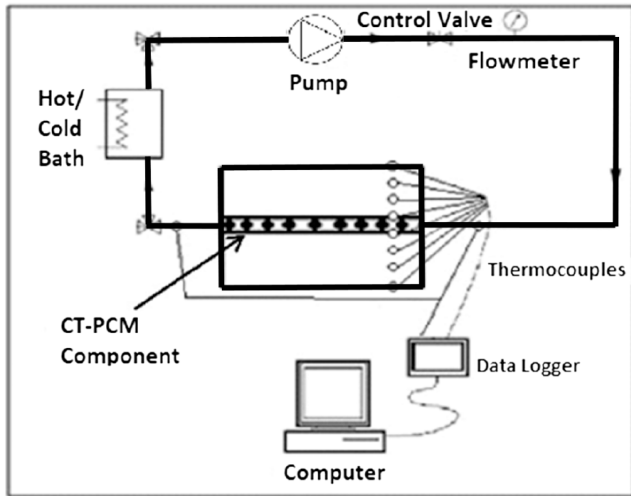
TES in high-rise building applications

TERMOBUILD™



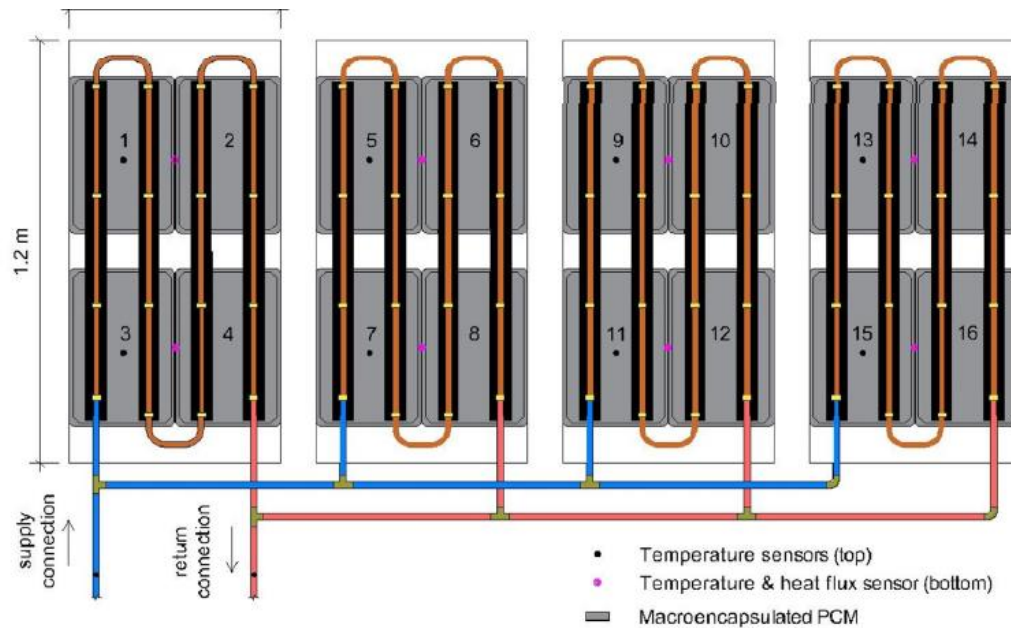
Ragubar and Berardi, 2019

“TABS” with Thermal Energy Storage



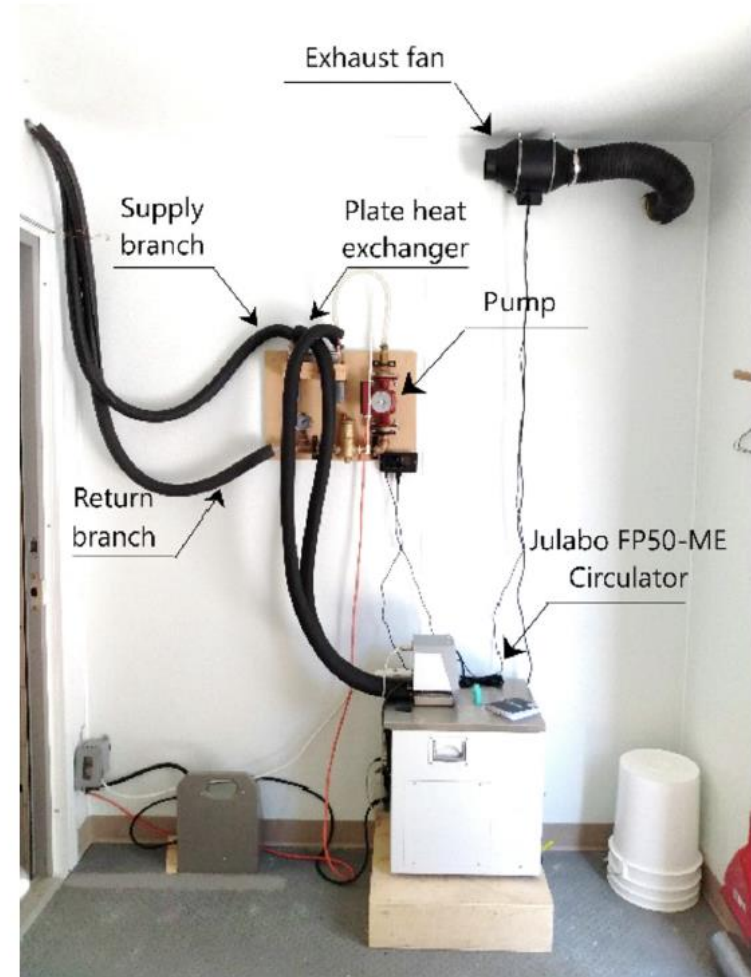
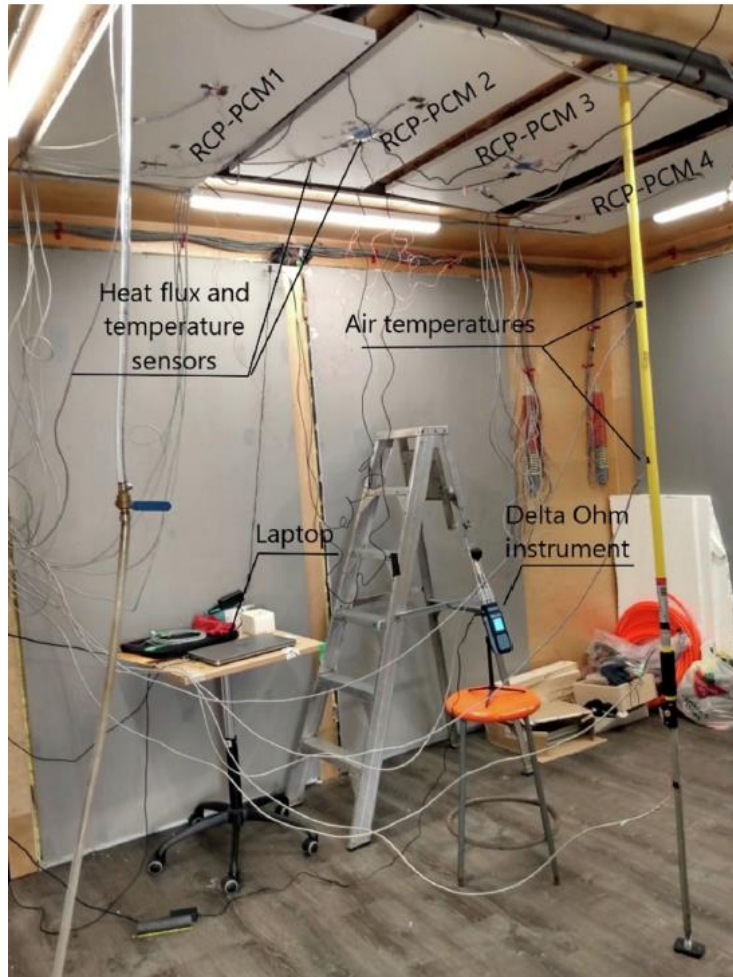
Berardi and Gallardo, 2022

“TABS” in RCP with Thermal Energy Storage



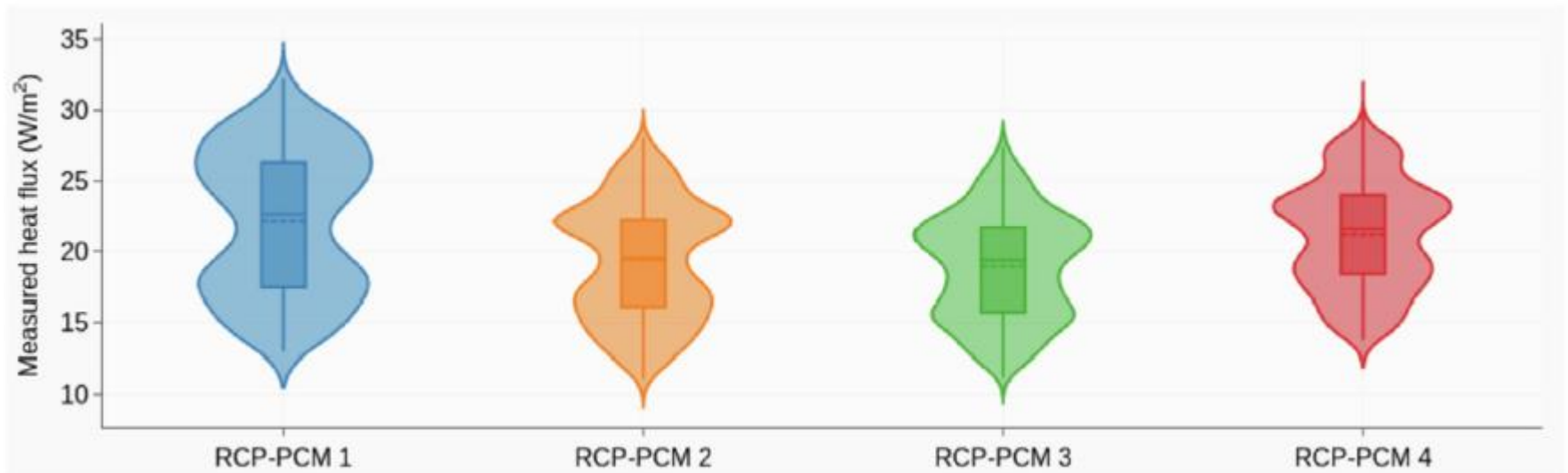
Berardi and Gallardo, 2022

“TABS” with Thermal Energy Storage



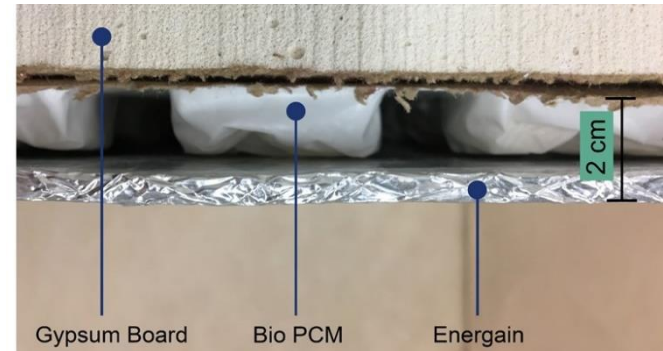
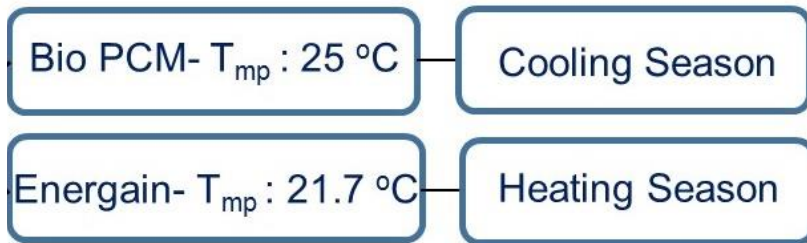
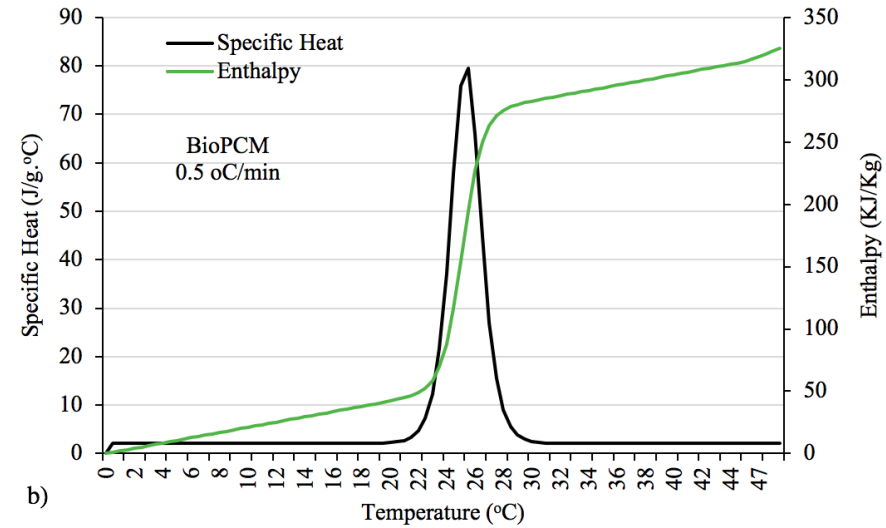
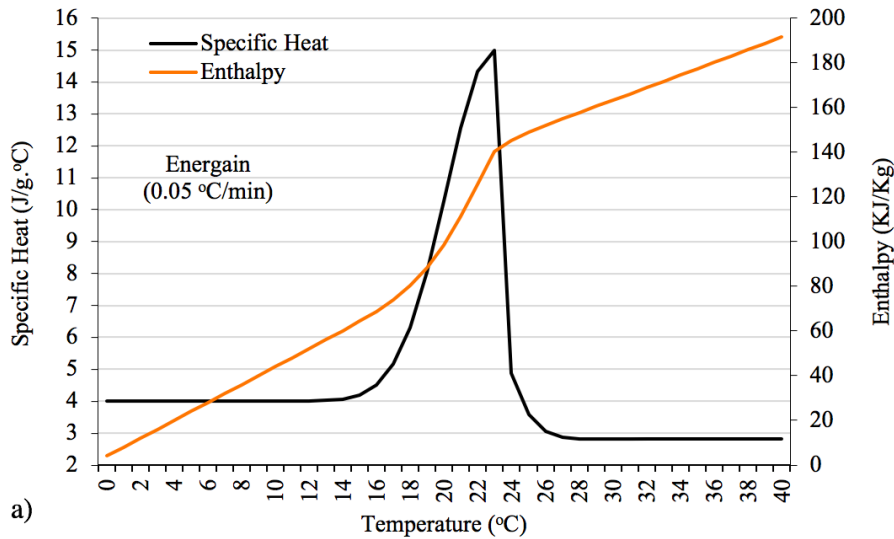
Berardi and Gallardo, 2022

“TABS” in RCP with Thermal Energy Storage



Berardi and Gallardo, 2022

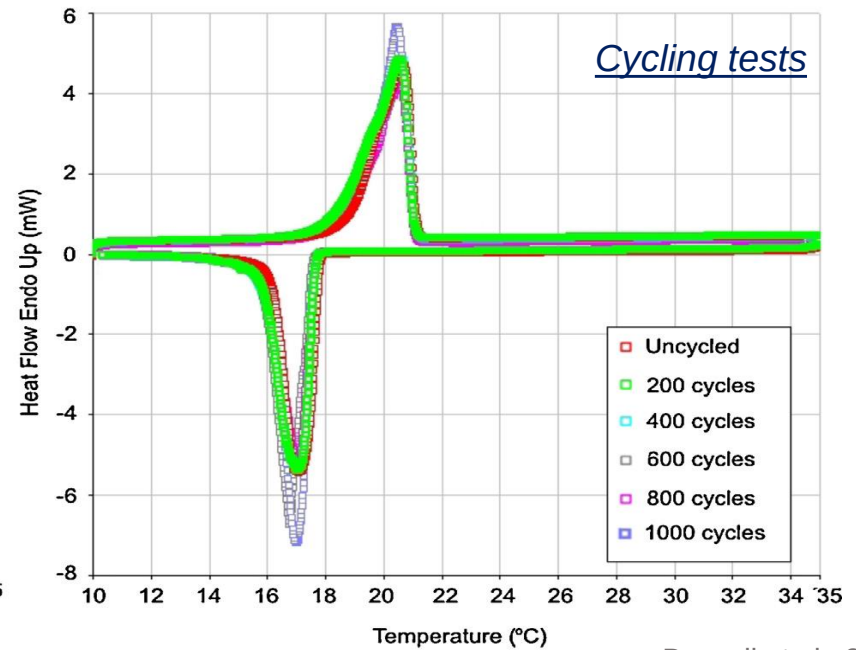
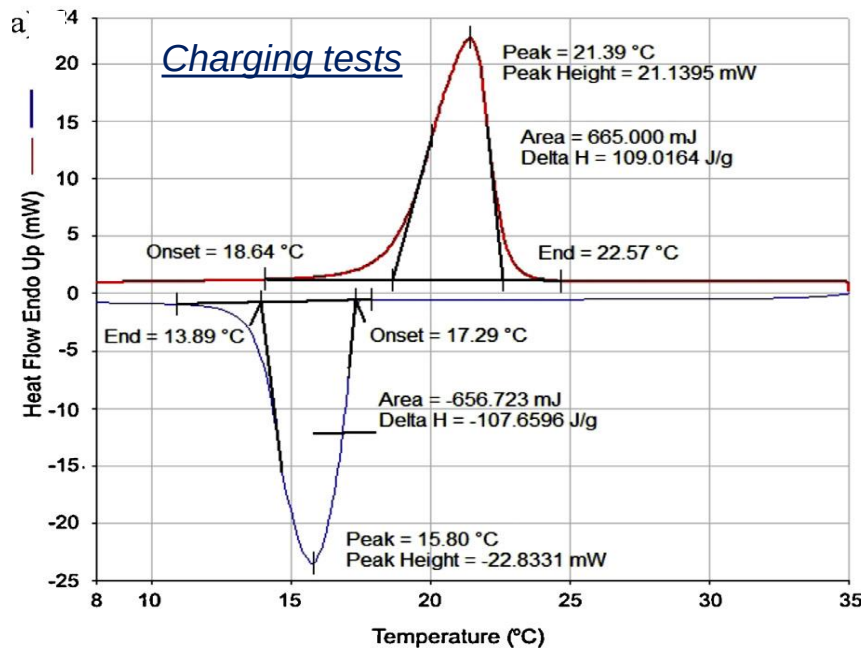
Coupling different PCMs



Soudian and Berardi, 2017, 2018

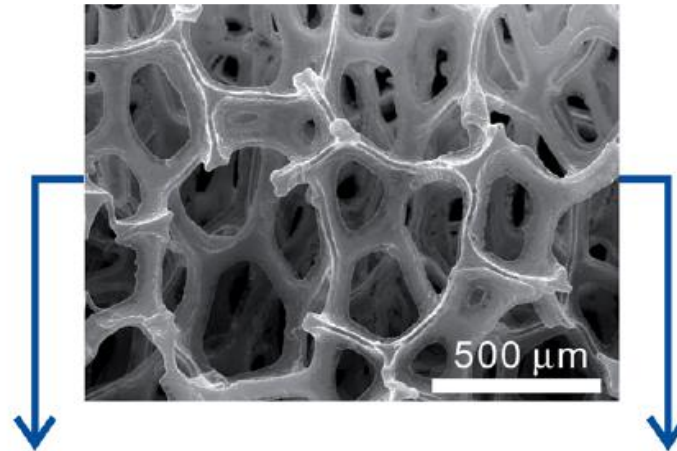
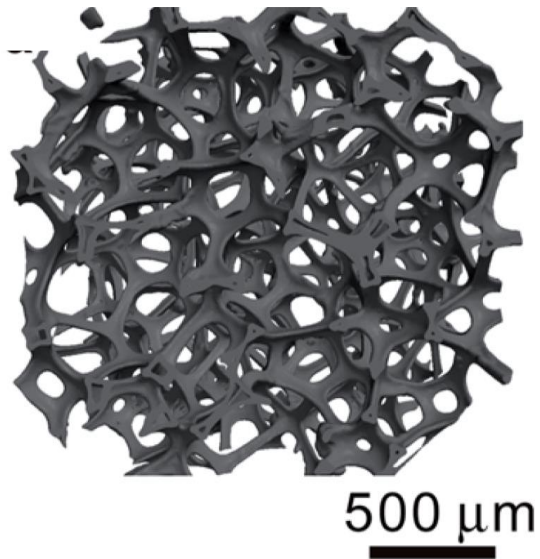
Bio-PCM enhanced systems

Bio-based PCMs derived from edible animal oils (fatty acids) have gained attention since they are not affected by price volatility and have a low environmental impact.

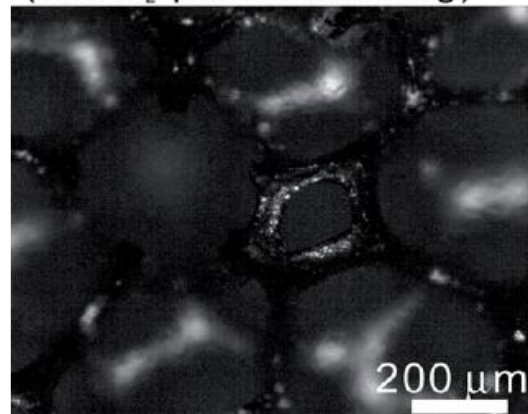


Berardi et al., 2016

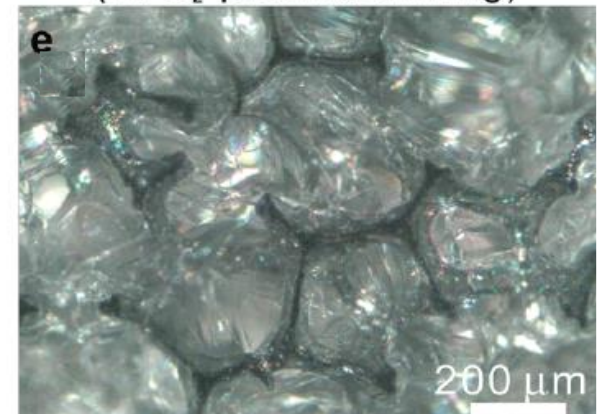
Graphene-enhanced PCMs



Hydrophobic PCM
Wax
(w/o O_2 -plasma & filling)

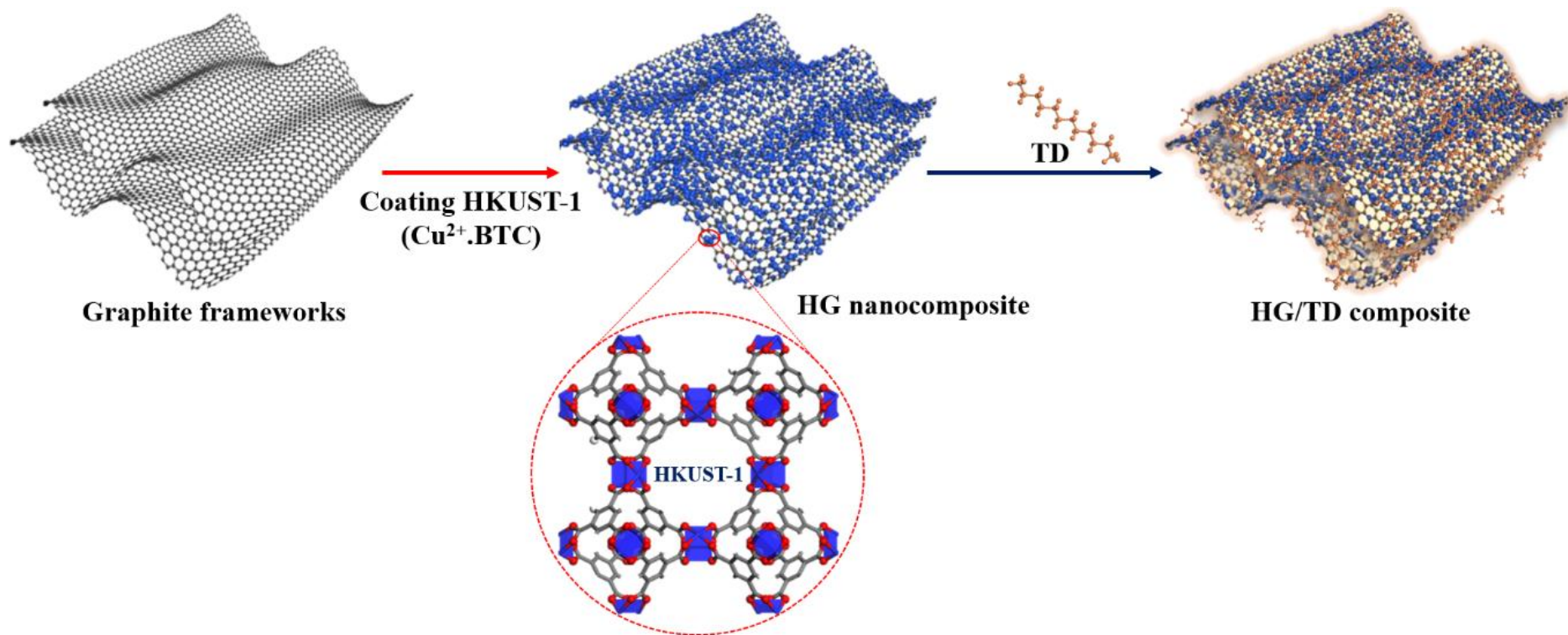


Hydrophilic PCM
Erythritol
(w/ O_2 -plasma & filling)



Berardi and Kim, 2020

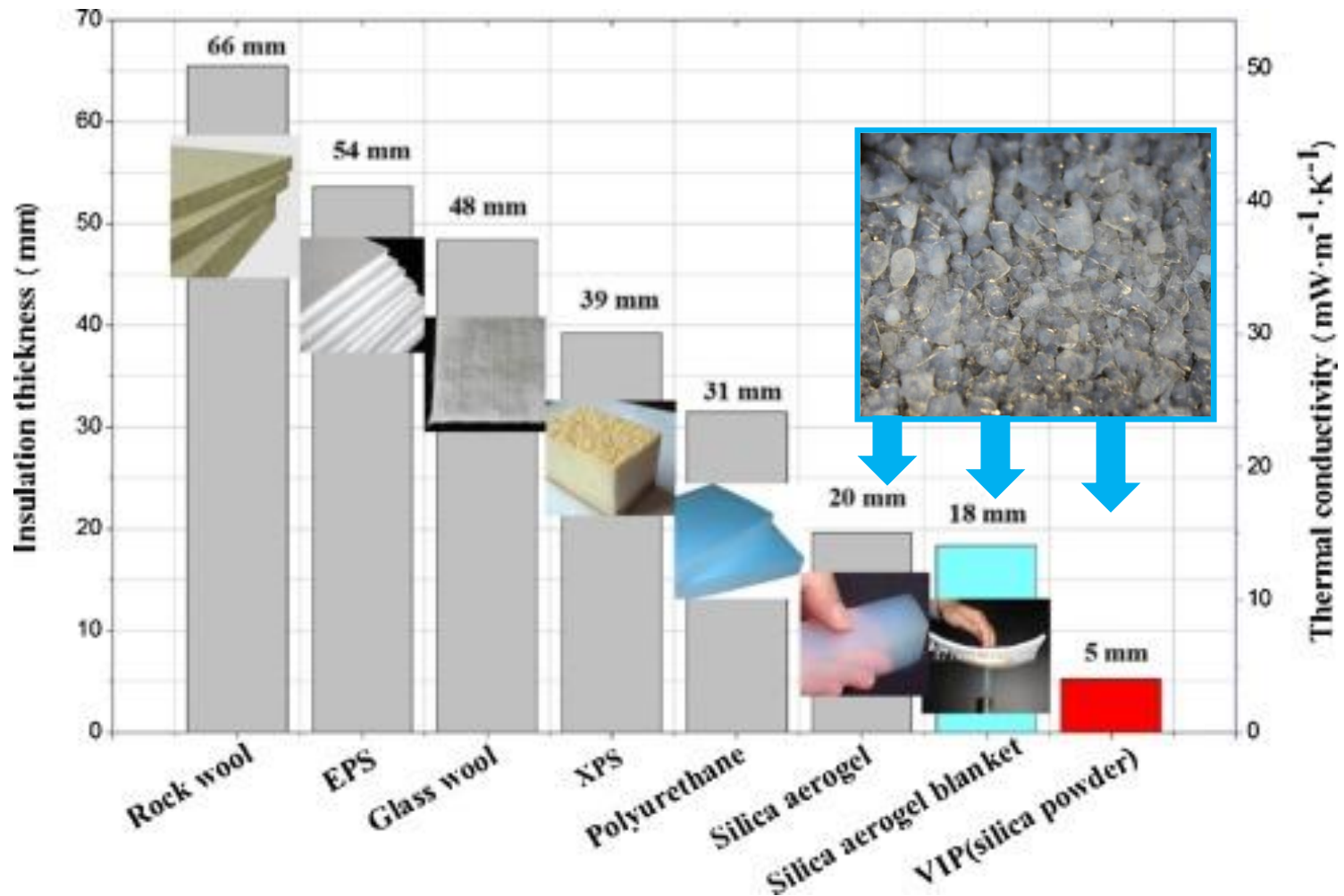
HKUST-1-graphite nanocomposite



Schematic description of a new composite phase change materials based on tetradecane and HKUST-1-based graphite nanocomposite.

Atinafu et al., Potential utility of HKUST-1-graphite nanocomposite to endow alkane with high thermal properties and low electrical resistivity, Journal of Hazardous Materials, 2021

Super-Insulating materials

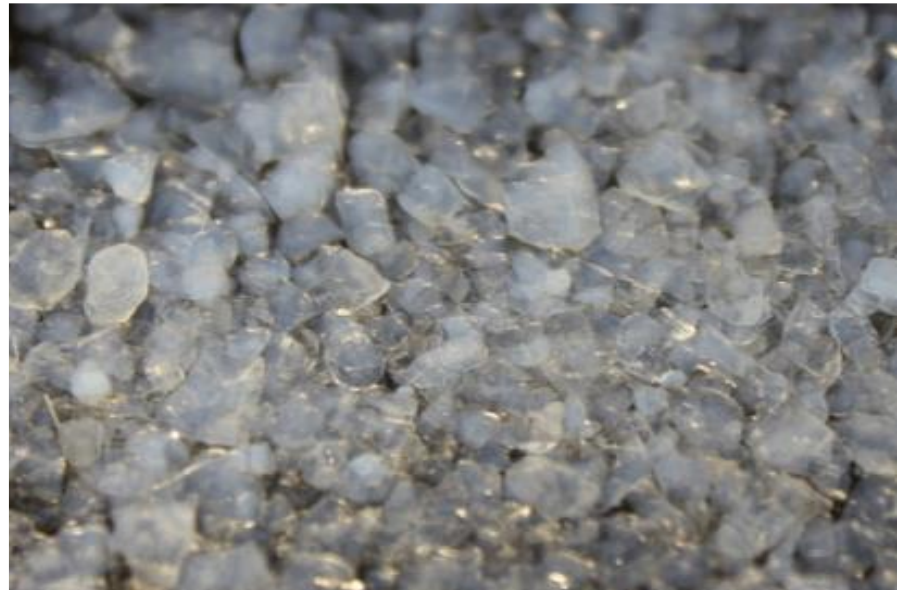


Aerogel

Aerogel is a mineral material made of amorphous silica with a nanoporous structure (nanopores from 20 nm to 80 nm).

Aerogel has 95–99% of the volume being air voids, resulting in extremely low density (3 kg/m^3) and low thermal conductivity (0.01 W/mK).

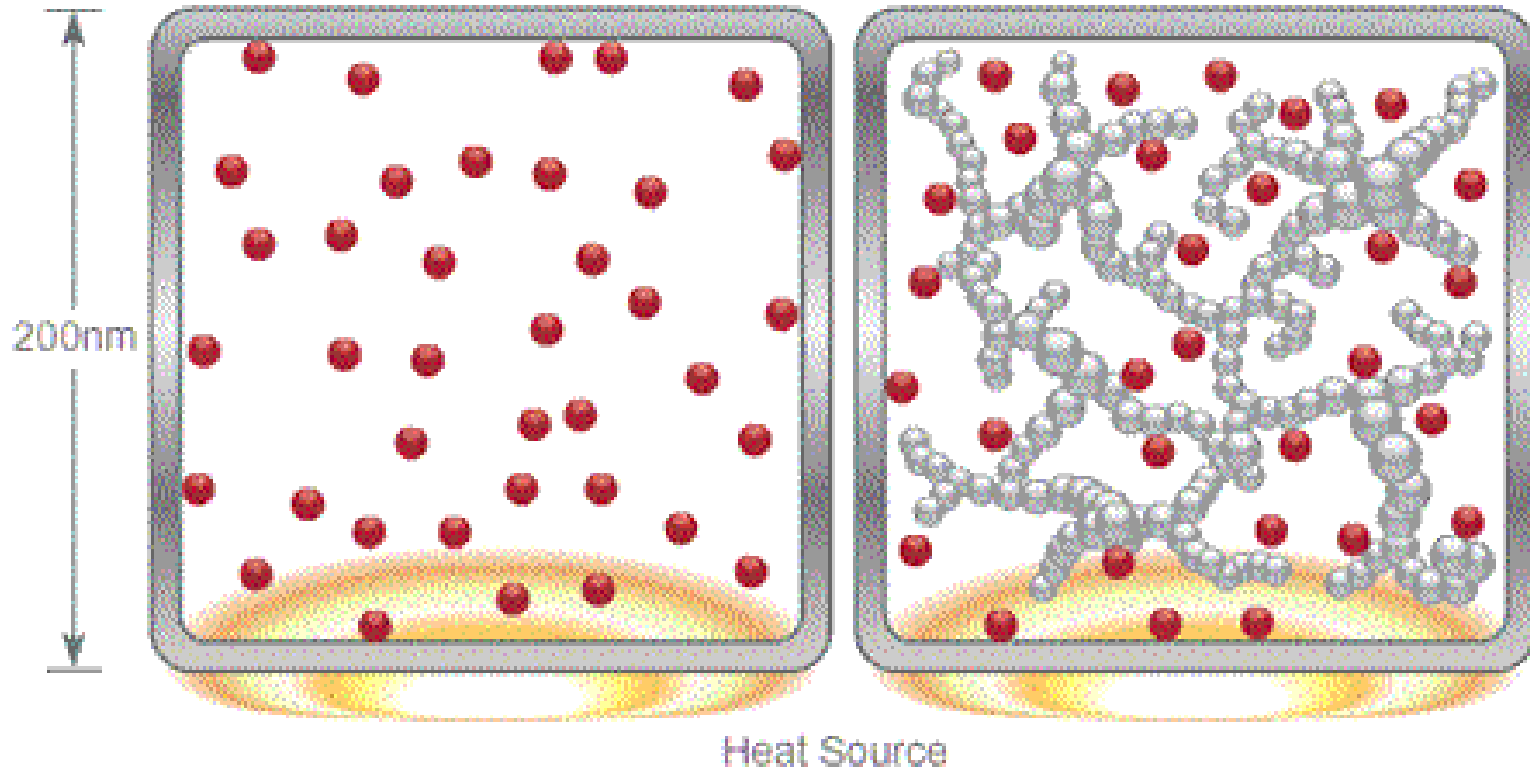
Aerogel is low flammable, lightweight, and air permeable.



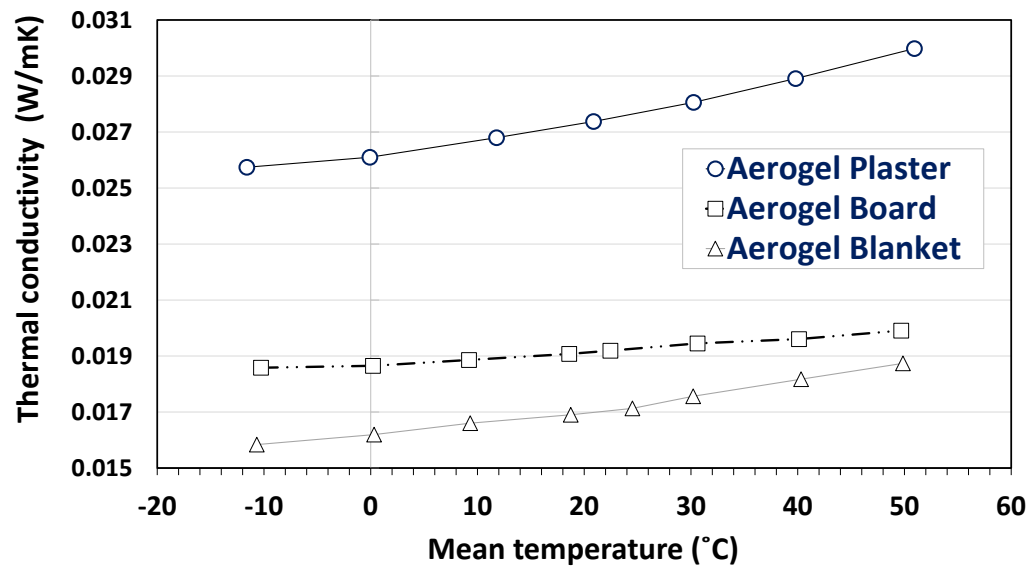
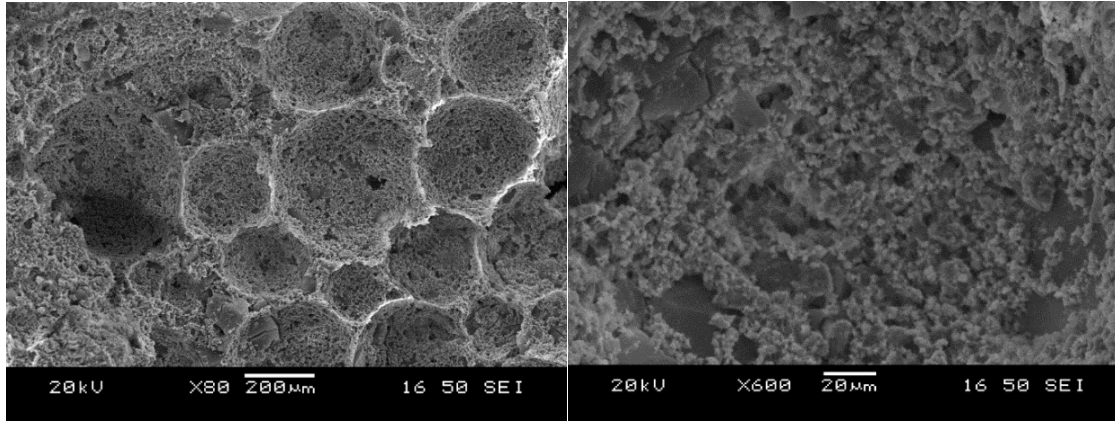
Aerogel

Gas molecules in conventional insulation materials

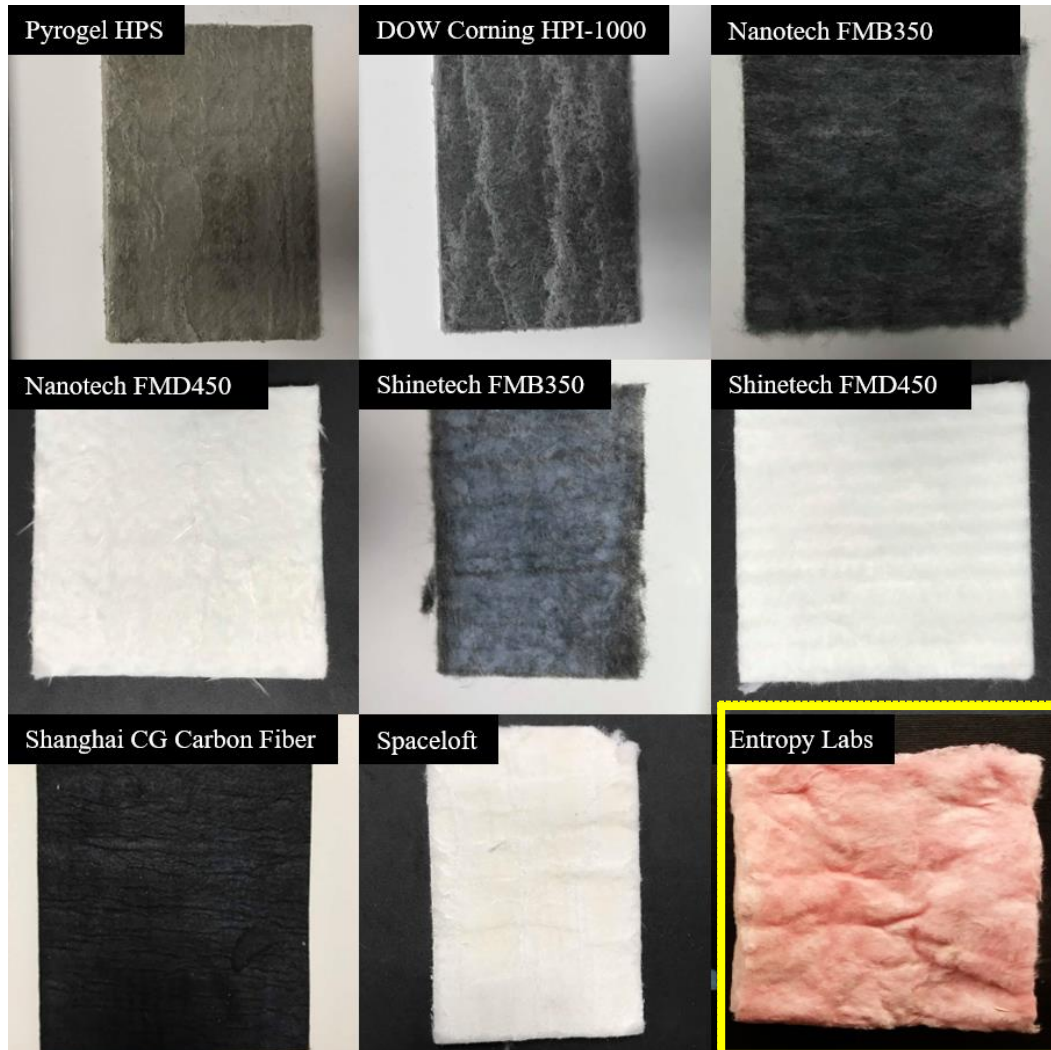
Gas molecules in aerogel granules



Aerogel in plaster



Aerogel-enhanced blankets



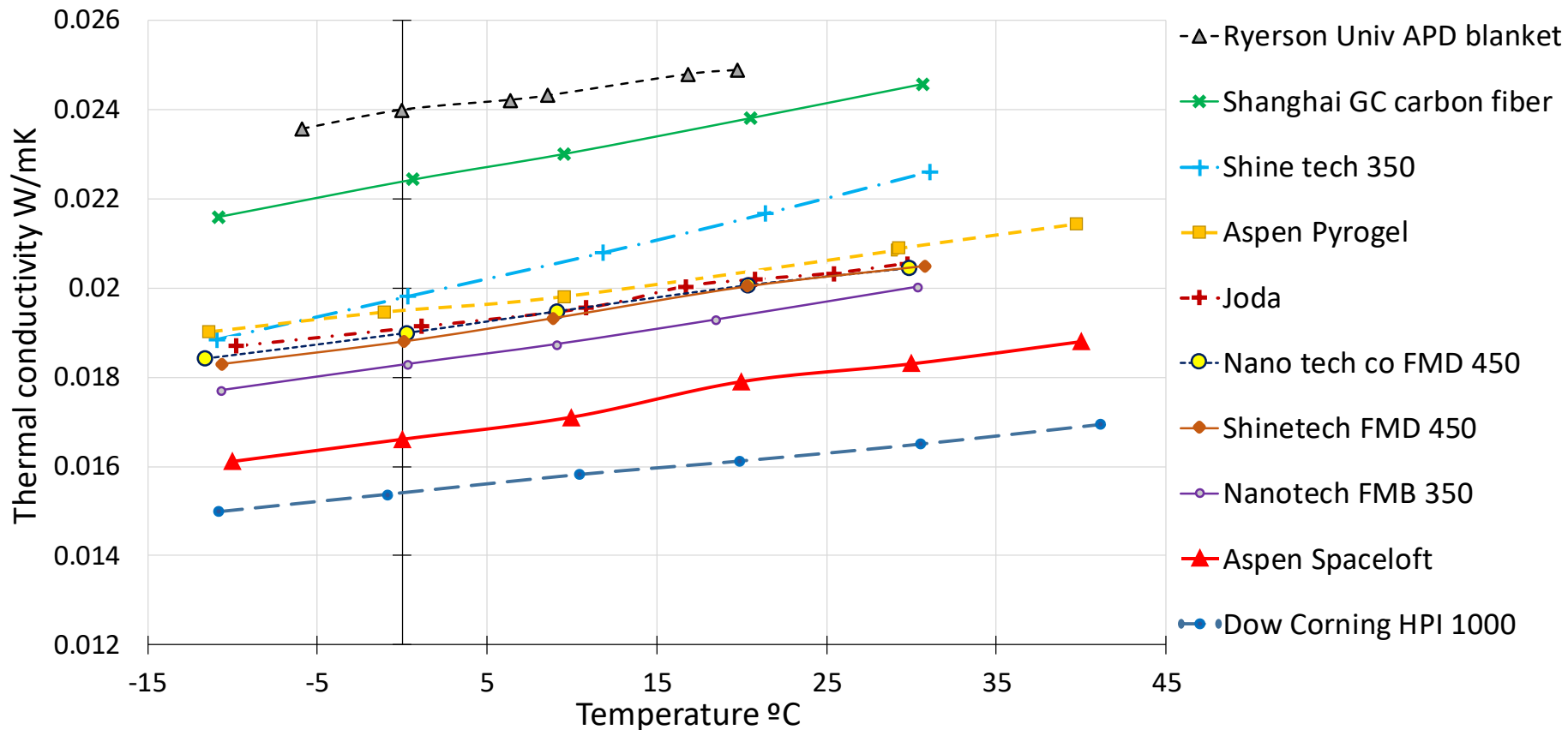
Photos of common commercially-available aerogel-enhanced blankets obtained using an S.C.D. process and of new blankets obtained using an A.P.D. process (*patented*)

(Entropy Labs Inc.).

https://www.youtube.com/watch?v=63r0oTEIXvQ&feature=emb_logo

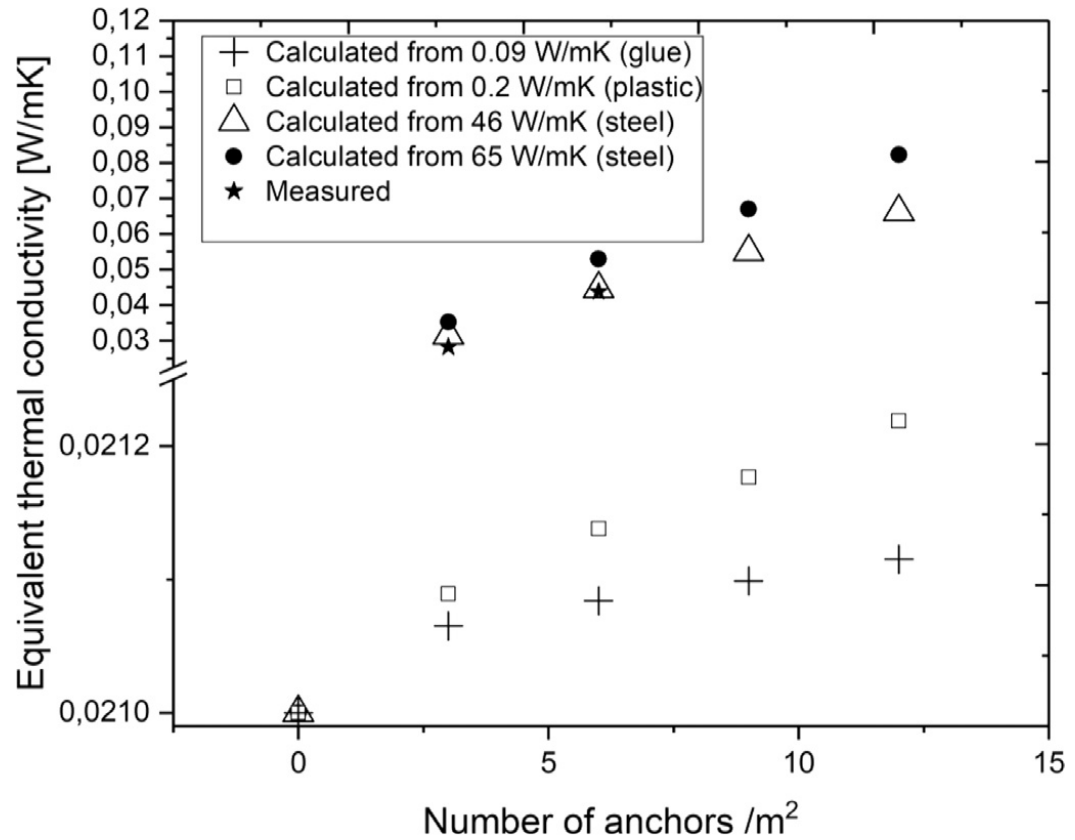
Berardi and Zaidi, 2019

Aerogel-enhanced blankets



Berardi and Zaidi, 2019

Fastening aerogel-blankets



Berardi and Lakatos, 2019

Aerogel in frames



Modified Frame	Frame profile (the aerogel is in azure)	Frame section	U-value W/m²K	Thermal field and isotherm
Case 2: aerogel inserted in the main central cavity only		jamb	1.101	
		head	1.127	
		sill	1.092	
Case 3: aerogel inserted in the two main central cavities		jamb	1.040	
		head	1.033	
		sill	1.032	
Case 4: aerogel inserted in all practical cavities		jamb	0.951	
		head	0.943	
		sill	0.944	
Case 5: aerogel inserted in all cavities		jamb	0.813	
		head	0.822	
		sill	0.824	

Berardi et al., 2020

Low Embodied Carbon Foams .. Beyond CFC!



Foam Insulation

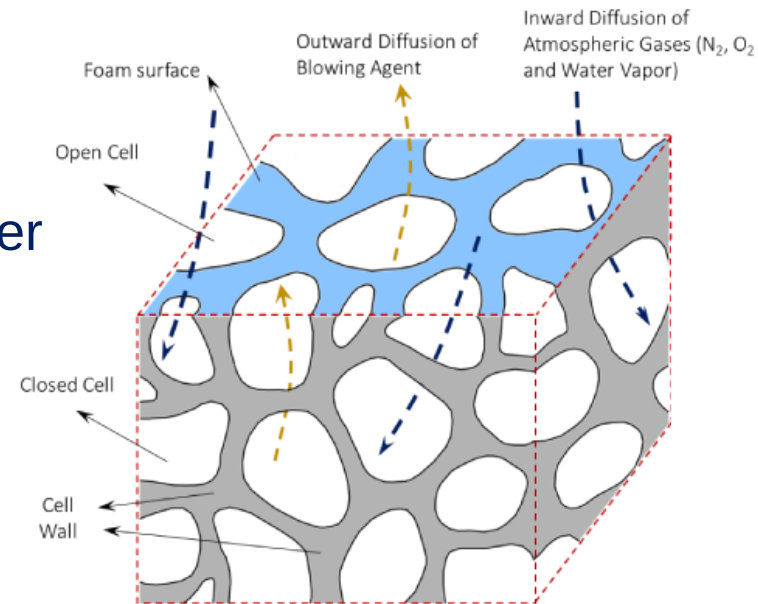


Foam chemistry had significantly changed

- I. The use of the *first-generation* of blowing agents known as chlorofluorocarbons, or **CFCs**, began in the mid-1900s
- II. To protecting the ozone layer, *second-generation* blowing agents, known as hydrochlorofluorocarbons or **HCFCs** were introduced
- III. HCFCs were phased out by *third-generation* blowing agents, called hydrofluorocarbons or **HFCs** (considered non-ozone-depleting)
- IV. Fourth-generation** blowing agents known as hydrofluoro-olefins or **HFOs**, have been introduced to offer no global warming potentials *Because water reacts and creates Carbon Dioxide, the GWP of the blowing agent is that of Carbon Dioxide (GWP=1).*

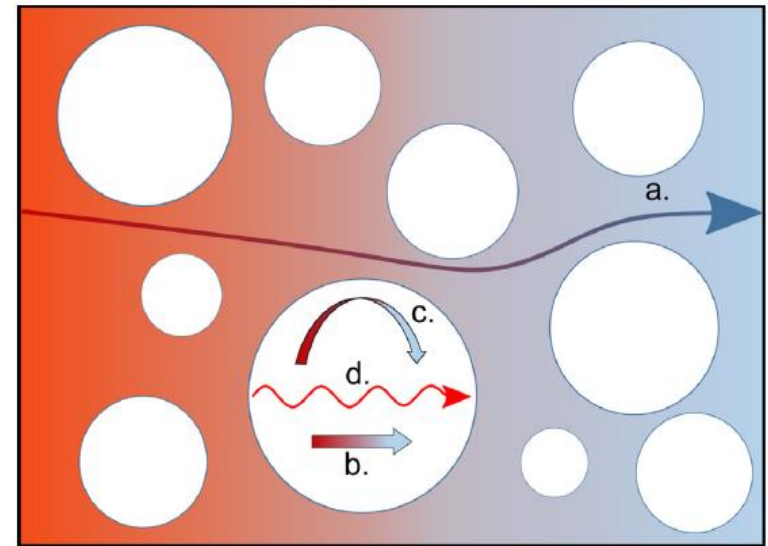
Causes of Foam Insulation Aging

- CO₂ outward diffusion (very fast, days)
- Air diffusion inward (fast, years)
- Moisture penetration
- Blowing agent dilution
- Blowing agent absorption in the polymer
- Blowing agent diffusion (very slow)
- Polymer degradation
- ..



Berardi and Madzarevic, 2020

Apparent thermal conductivity

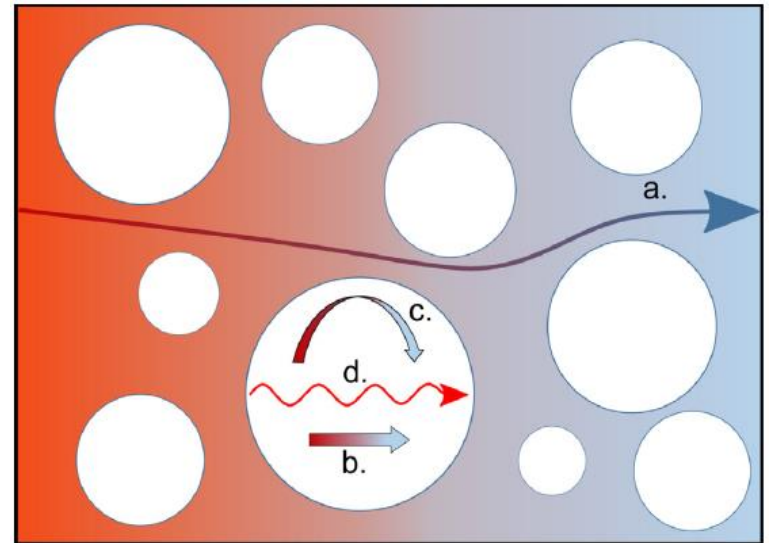


The interactions among the three modes of heat transfer determine the overall effectiveness of heat transfer through a porous material and are represented by its “apparent thermal conductivity”.

This term is used to indicate the lack of a “pure conduction” mode of heat transfer in porous materials.

Together with heat transfer modes, phase changes of vapor moisture, although not strictly an energy transfer mechanism, should also be considered in heat transfer analysis

Apparent thermal conductivity



The solid conductive portion is approximately linear with foam density, ranging from less than 5% to more than 40% as foam ranges from 10 to 80 kg/m³.

The gas conductivity depends on the gas mixture within the cells. In new foam, the gas contributes from ~ 40% for foams filled with low-conductivity blowing agents; up to ~70% for foams filled with air.

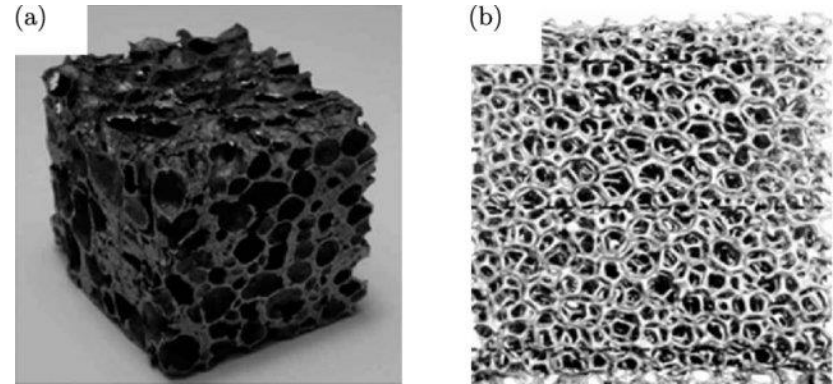
The remainder of the total conduction is due to gaseous conduction. The equilibrium among the different gasses in the material changes over time.

Berardi and Madzarevic, 2020

Standard measurements of the Heat Flow/Flux

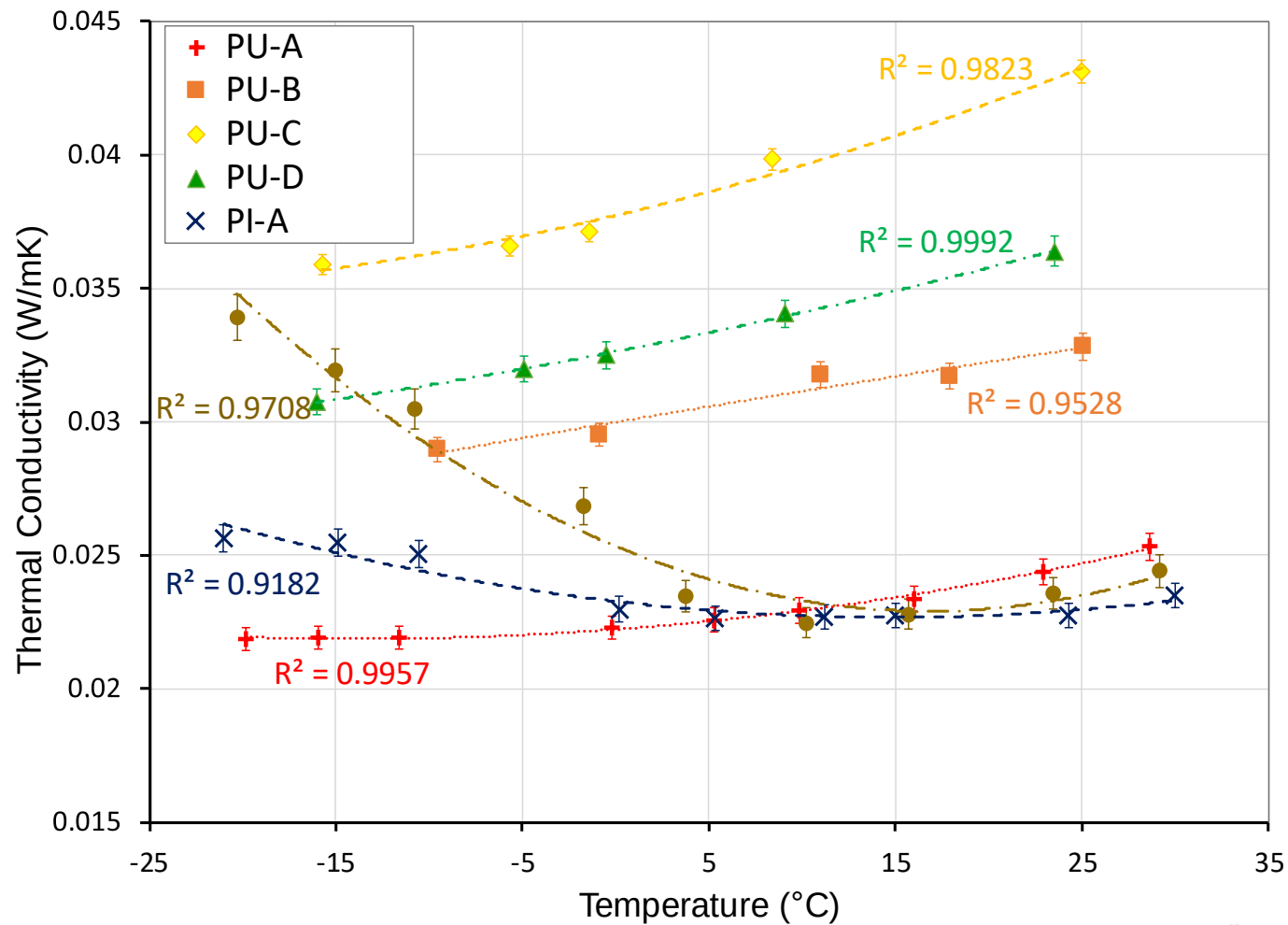
The definition implies many assumptions:

- Material is homogenous
- No temperature sensitivity
- No thermal storage: “*thermal mass of the material is neglected*”
- No airflow sensitivity
- Only Heat transfer by conduction occurs (..) otherwise:
 - what if the same material/same thickness is oriented vertically or horizontally?
 - what if the warmer side (surface) is above or below?



Berardi and Madzarevic, 2020

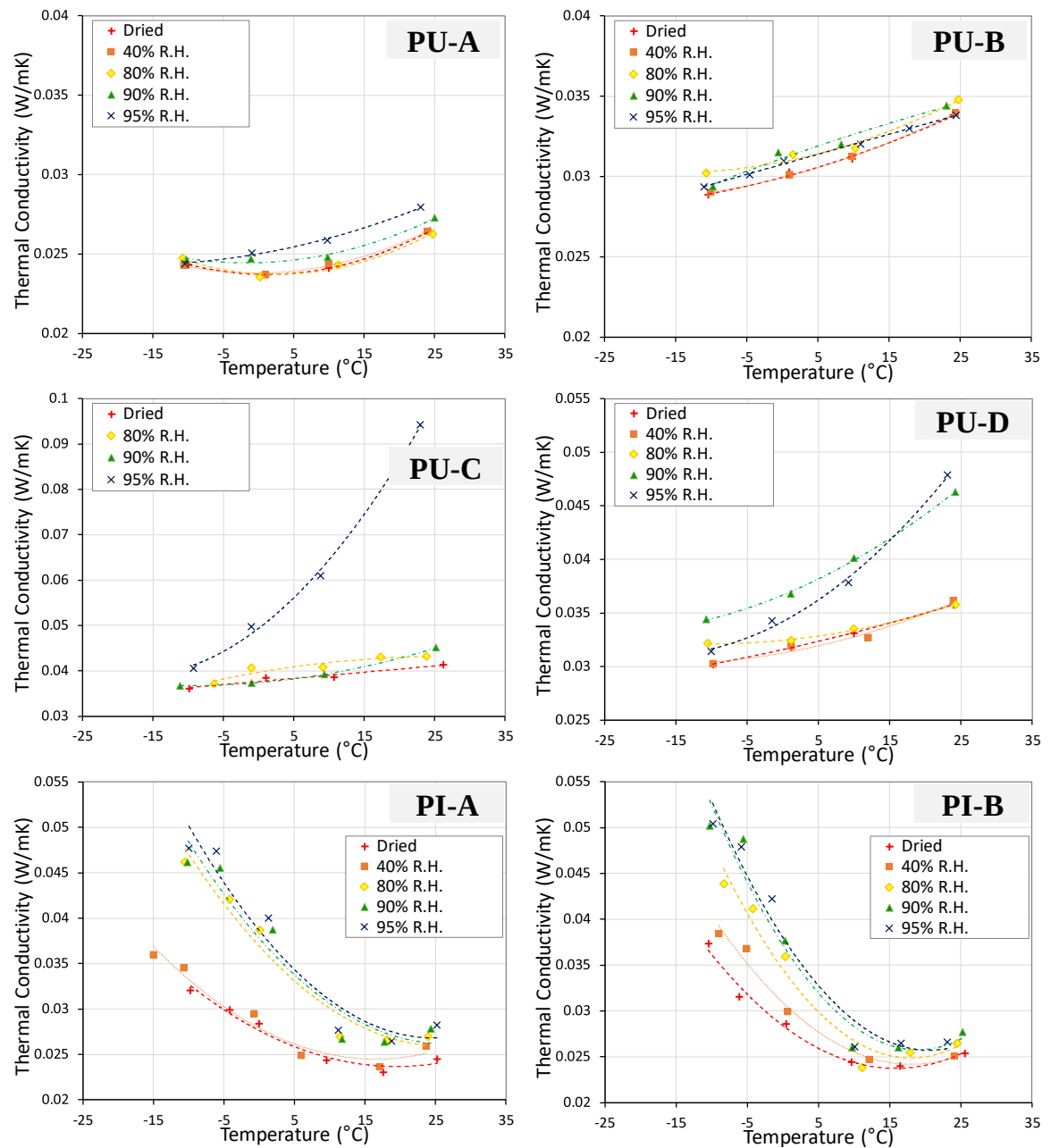
Temperature influence



Berardi and Naldi, 2018

Moisture influence

Effective thermal conductivity of the different foam materials after exposure to different relative humidity levels.

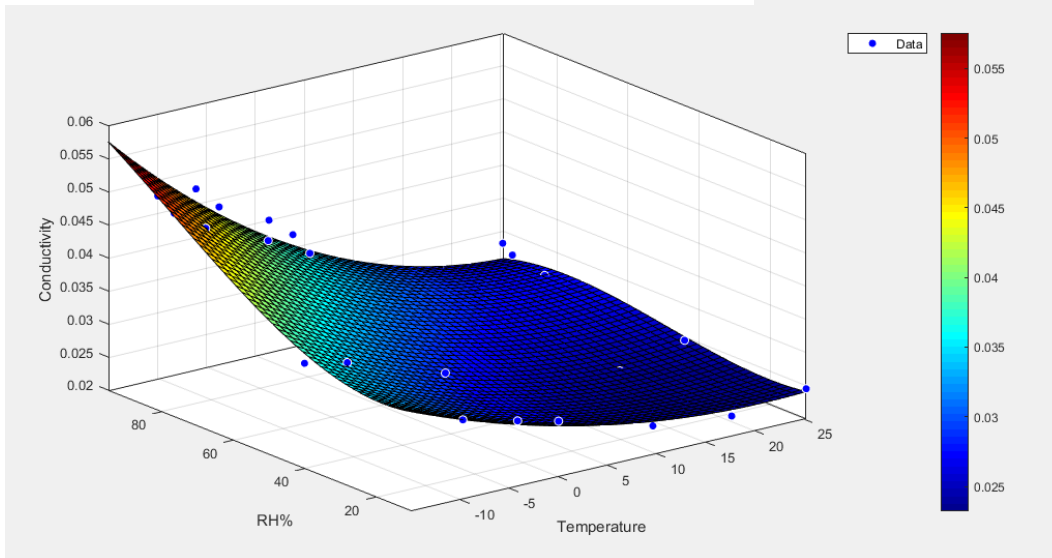
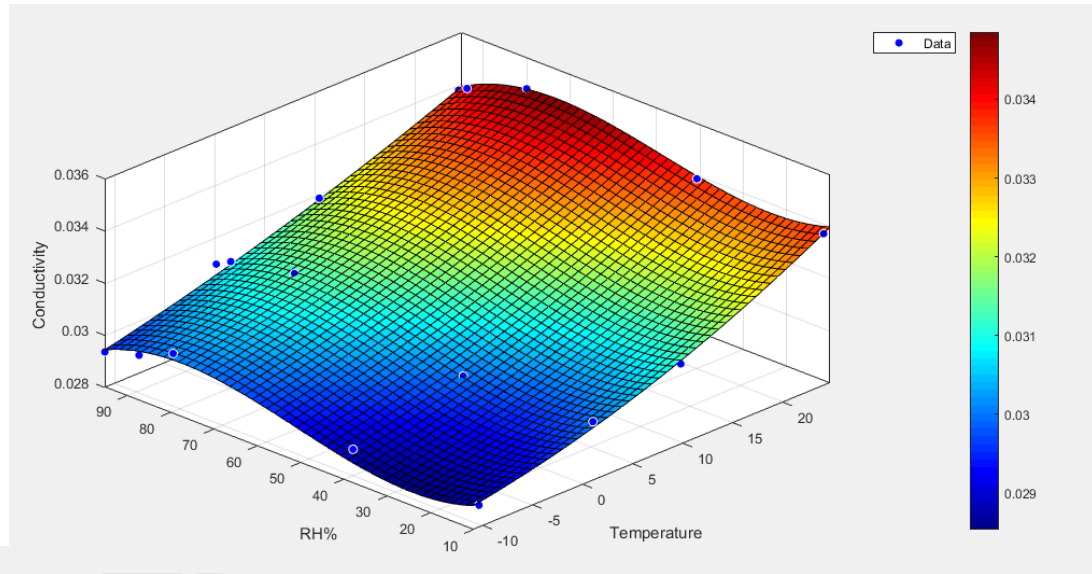


Effective behaviours of foams

ASTM C 518 (2017)

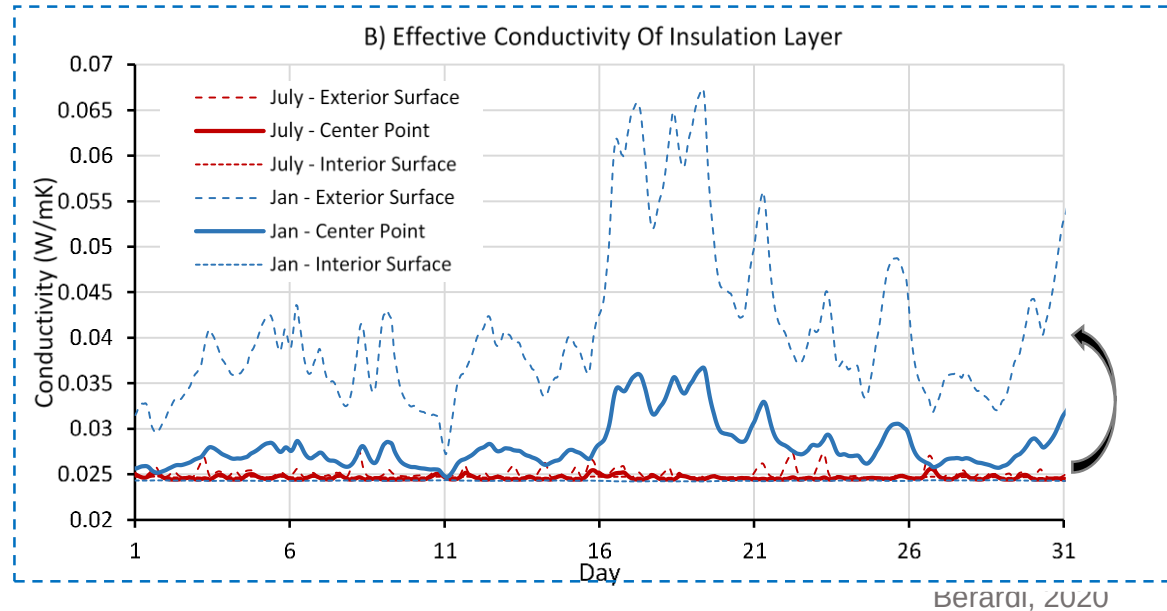
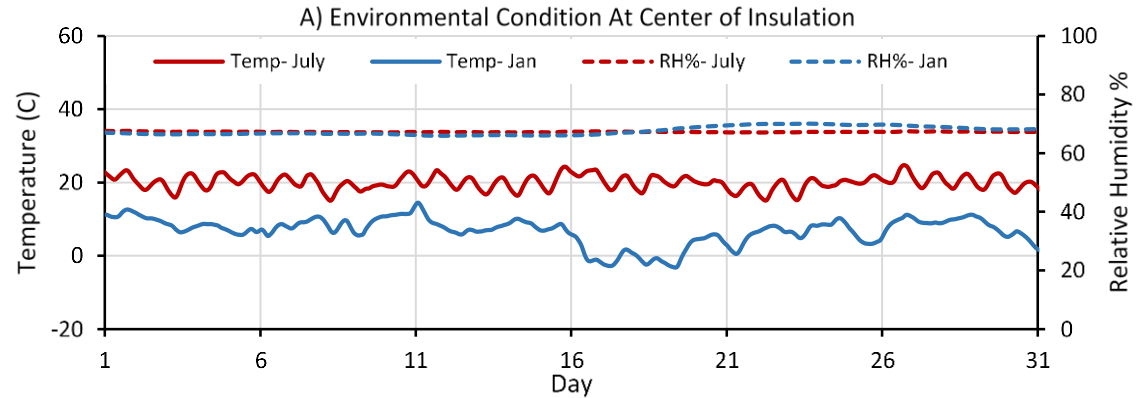
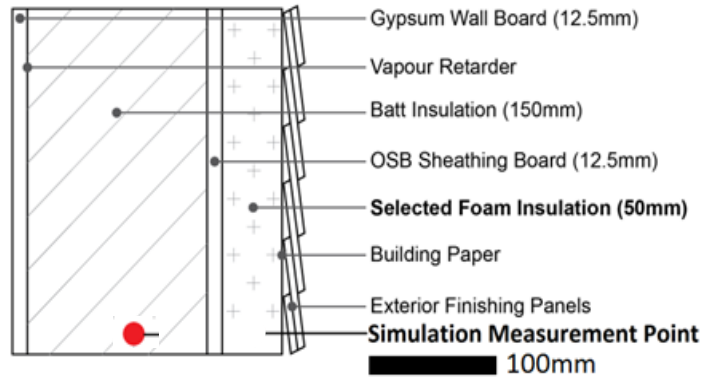


ASTM C1058 (2015)



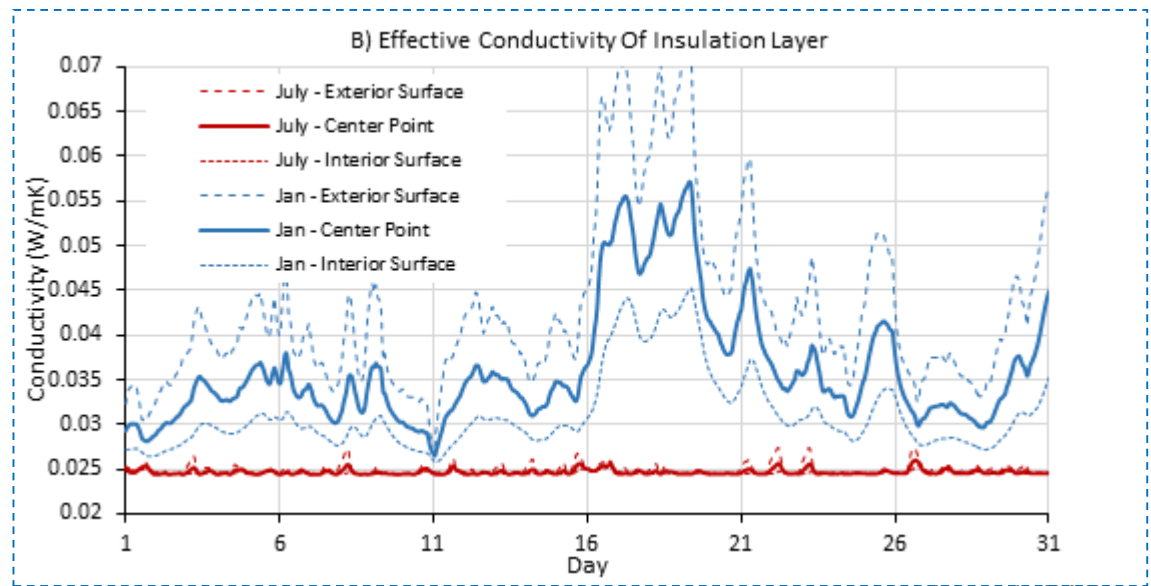
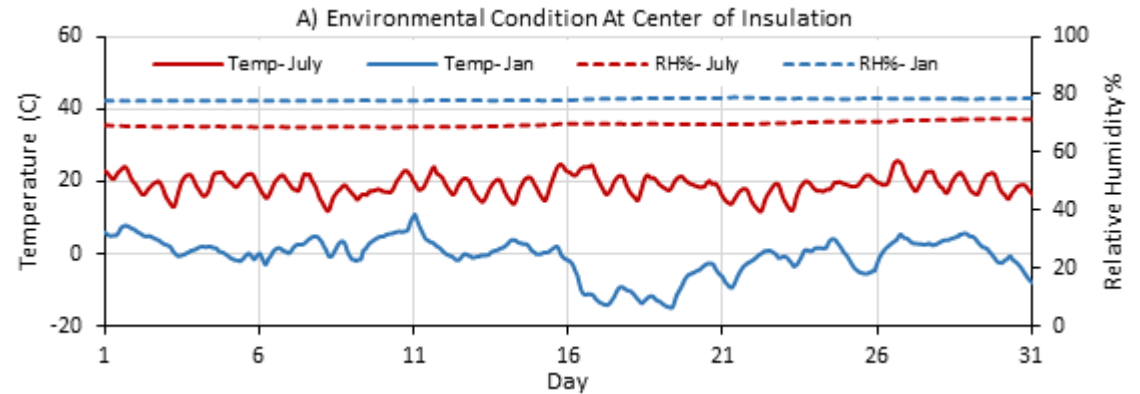
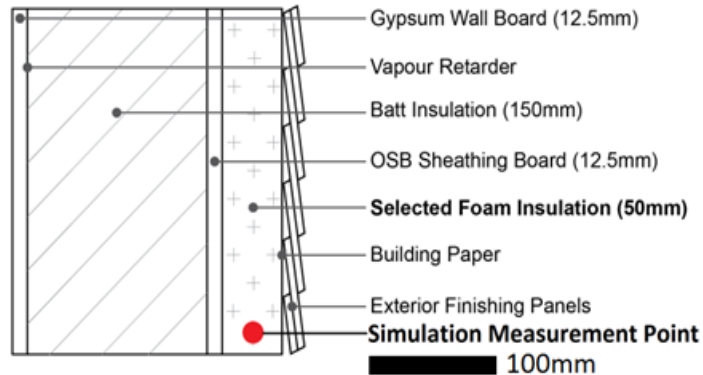
Berardi, 2020

Effective Behaviour of interior.. (in Toronto)



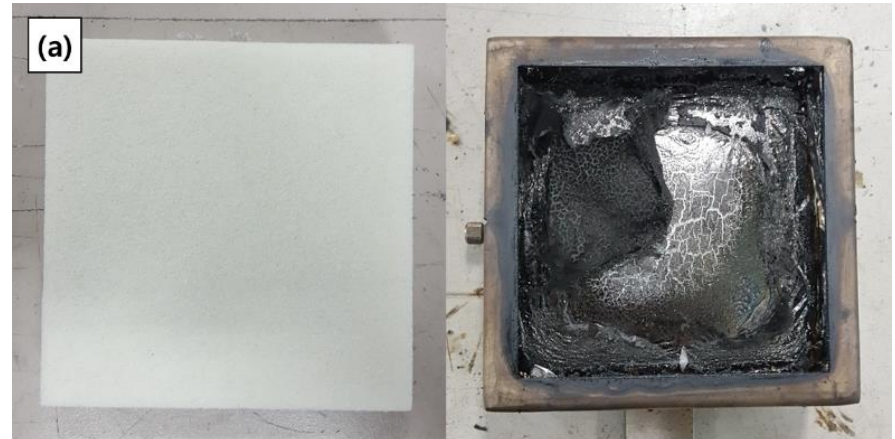
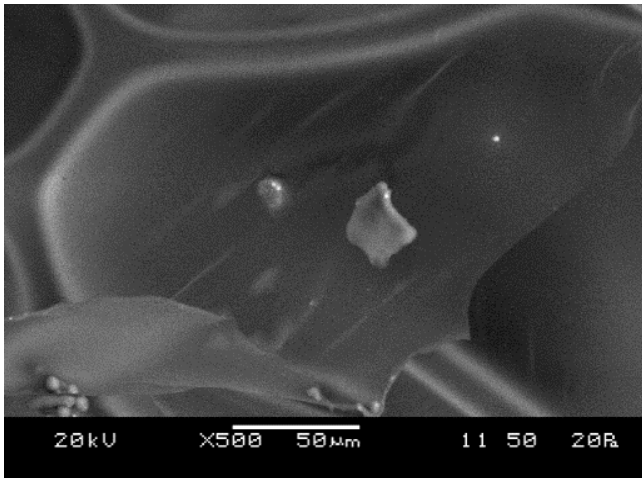
Berardi, 2020

Effective Behaviour of exterior .. (in Toronto)



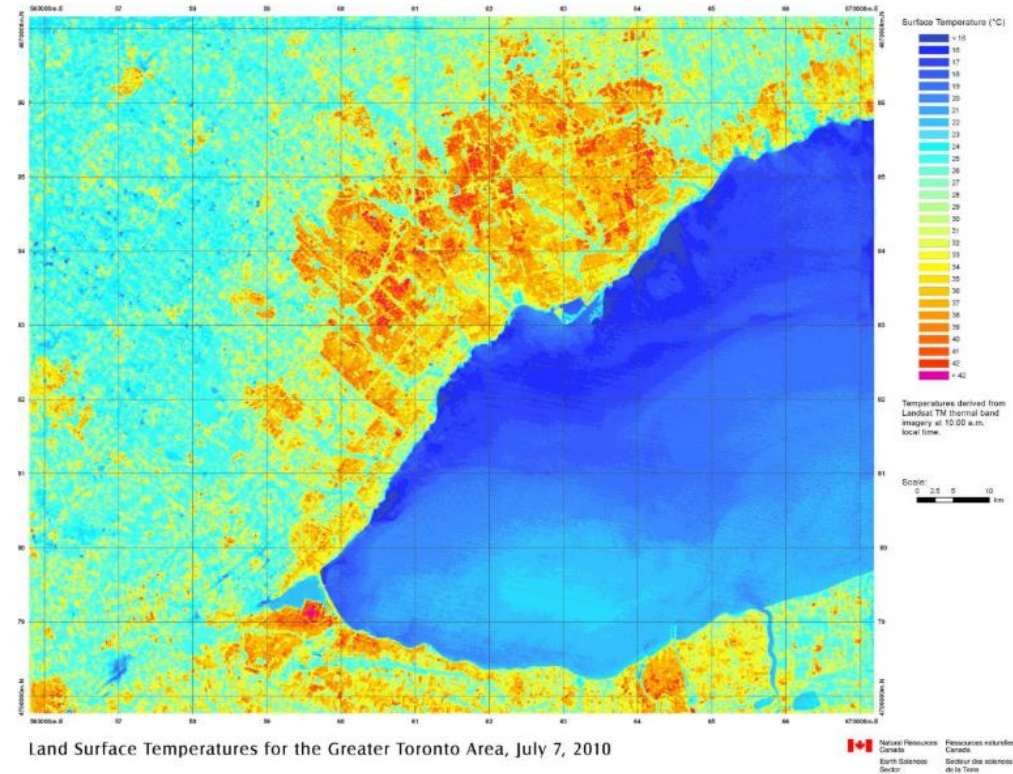
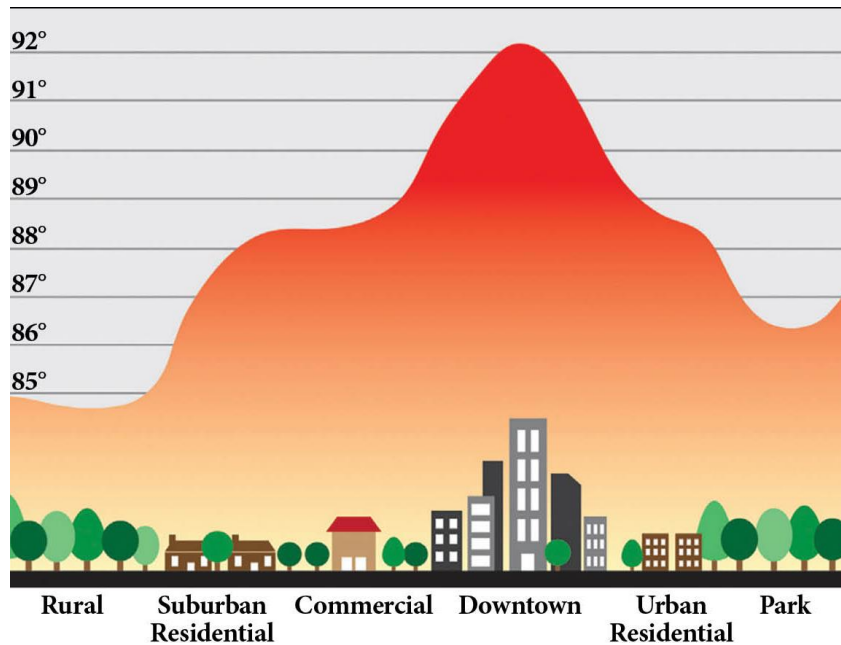
Berardi, 2020

New foams: Aerogel-enhanced Fire-resistant Polyurethane

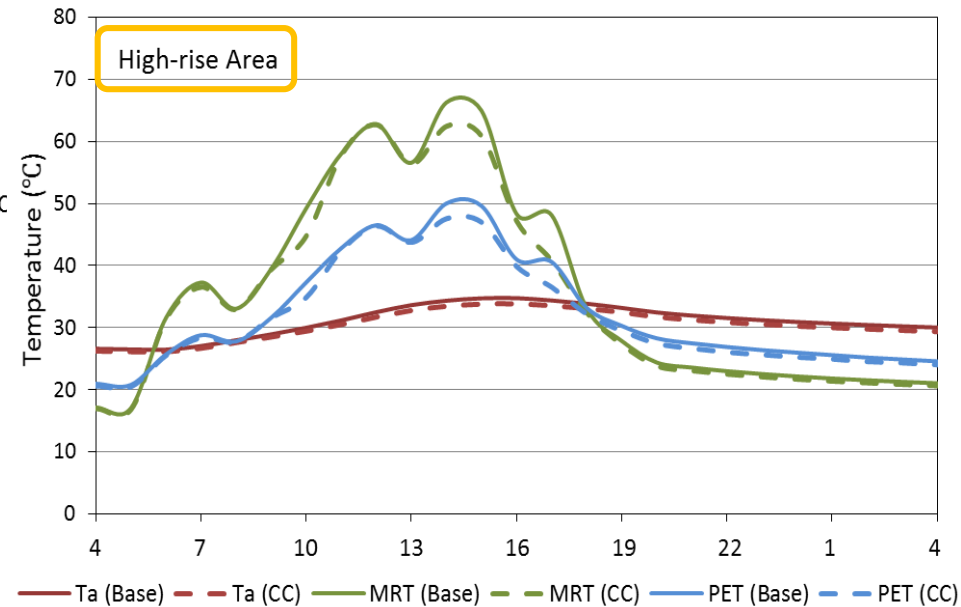
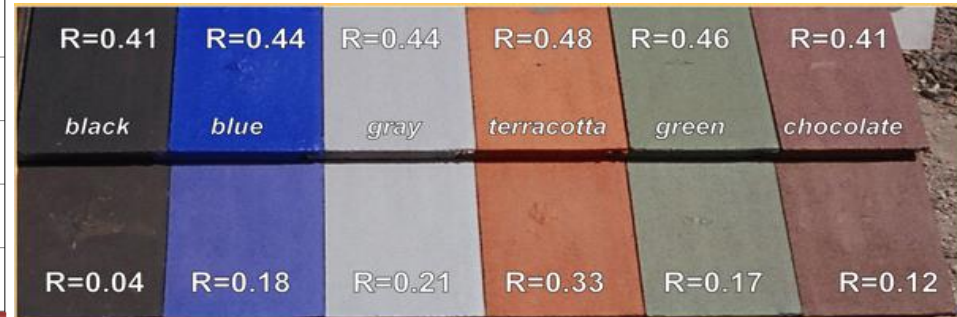
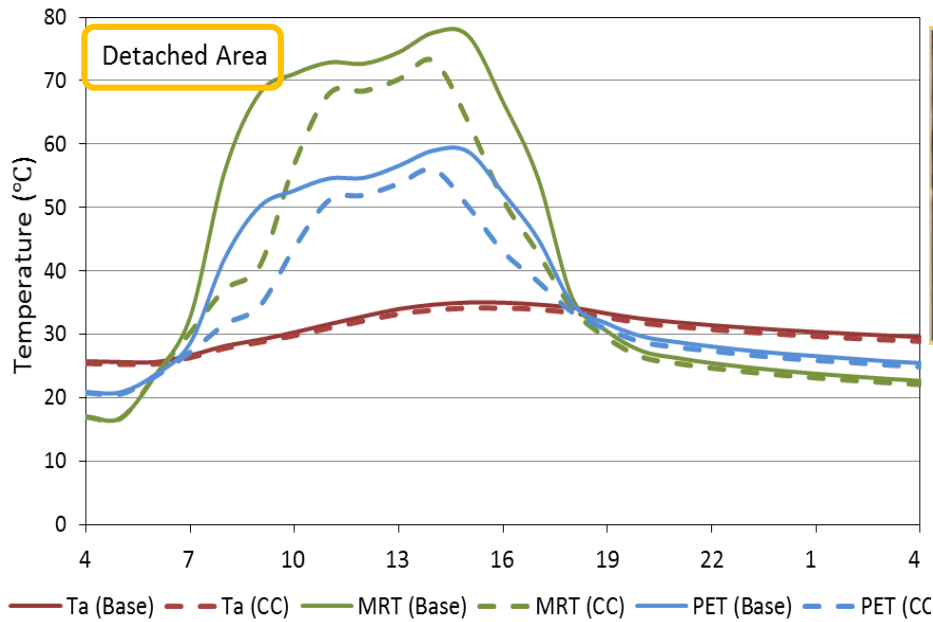


Berardi et al. , 2021

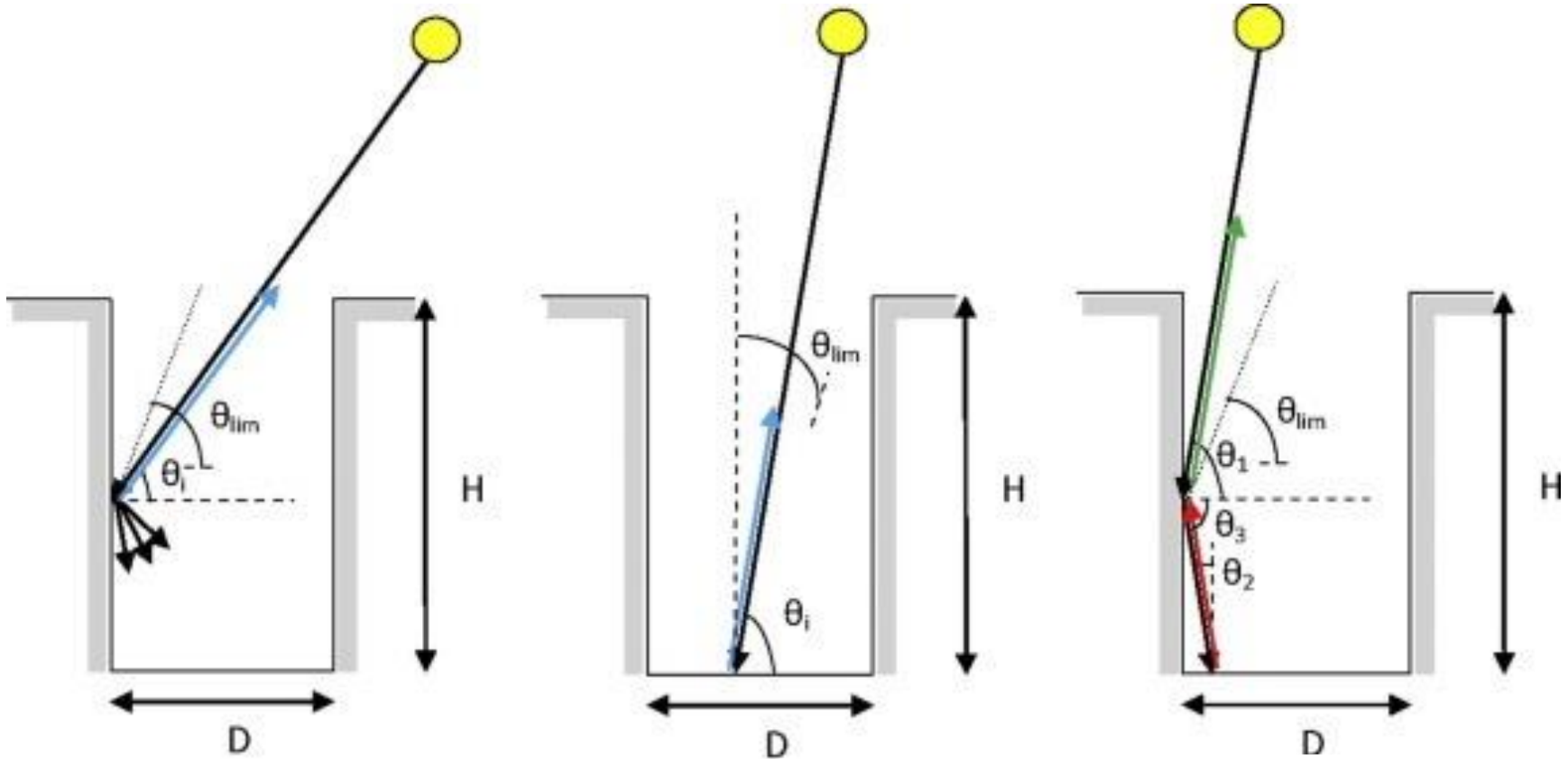
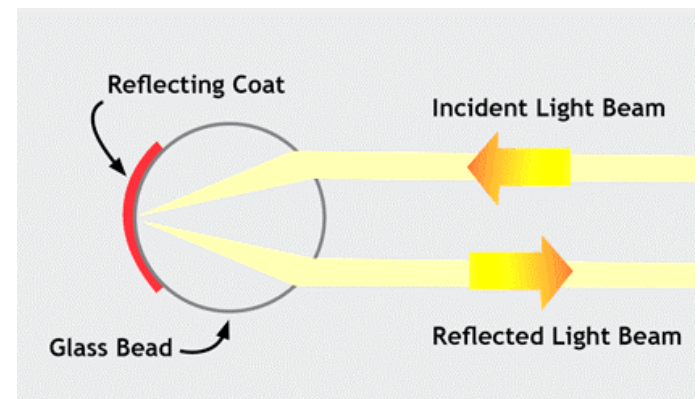
New materials to mitigate Urban Heat Island effect



High-albedo materials (cool pavement and roofs)

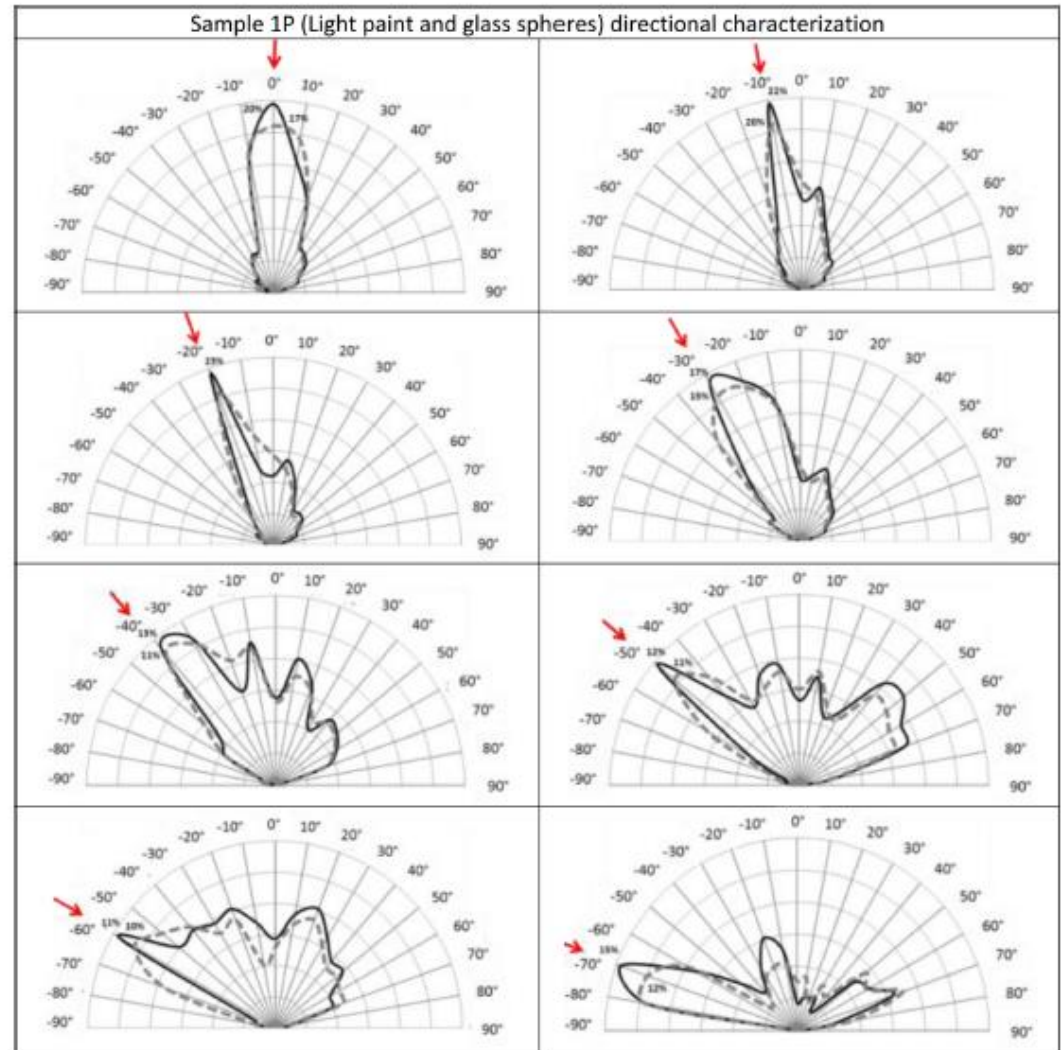
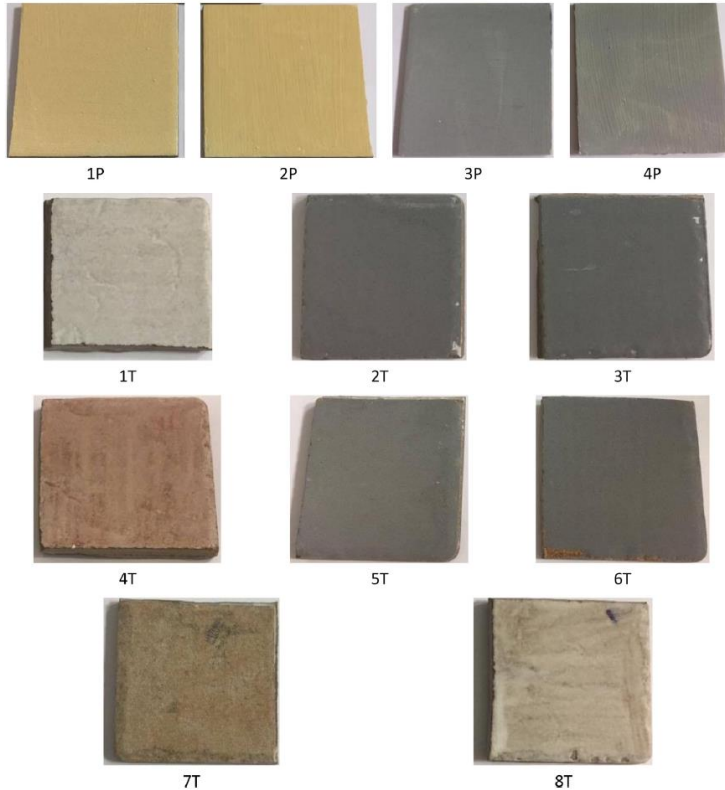


Retroreflectivity materials



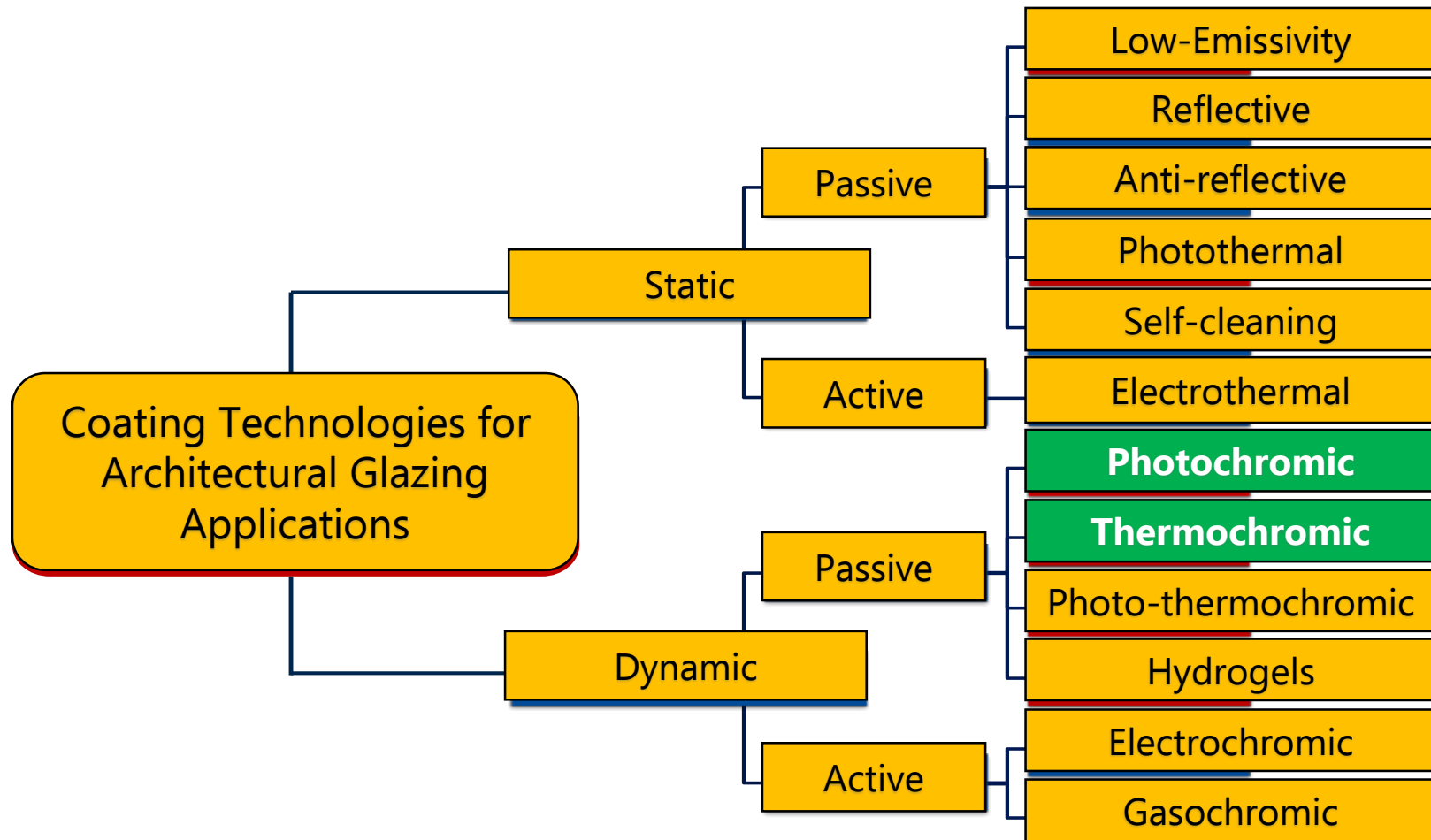
Rossi and Berardi, 2018

Retroreflectivity materials

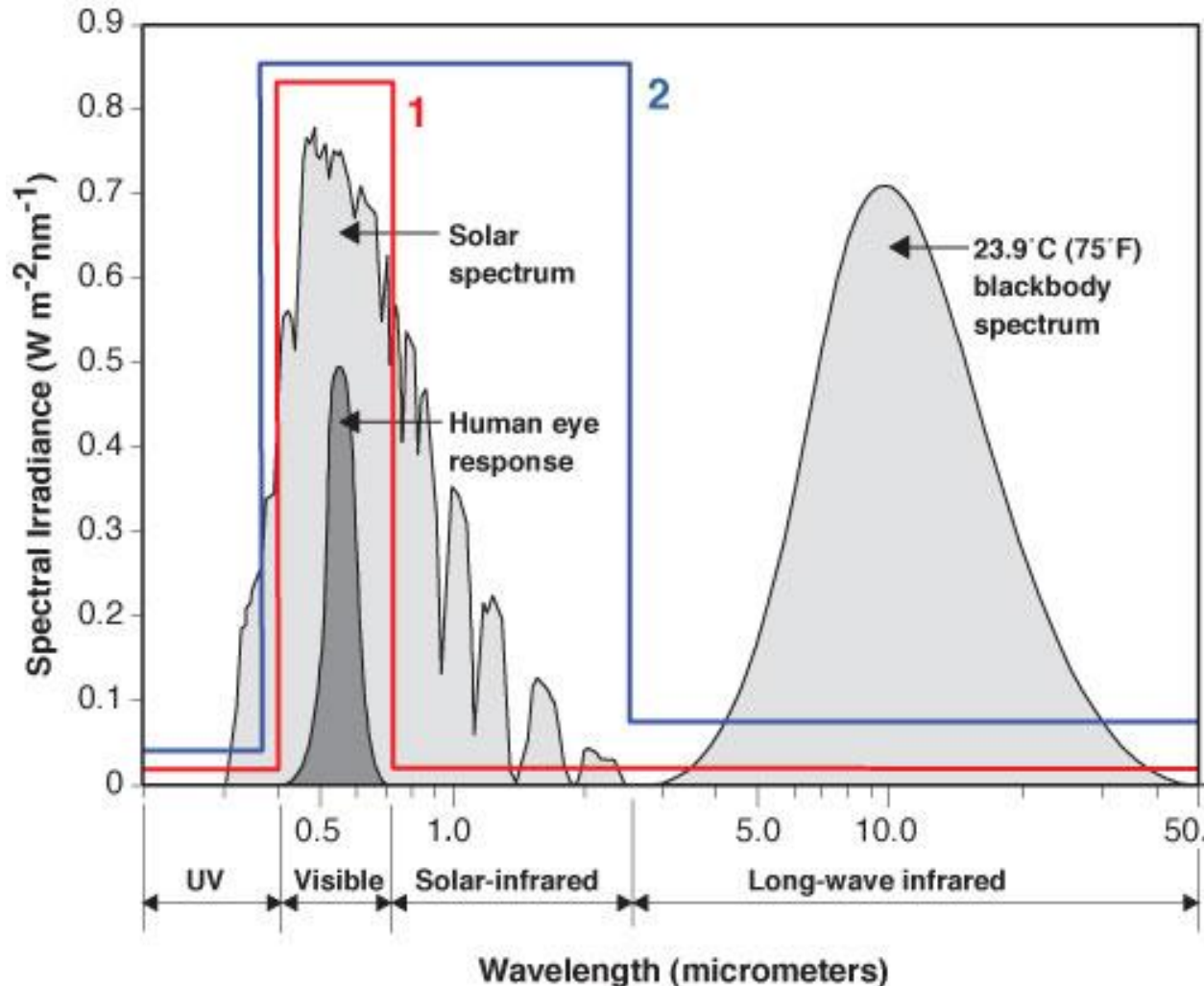


Rossi and Berardi, 2018

Window films



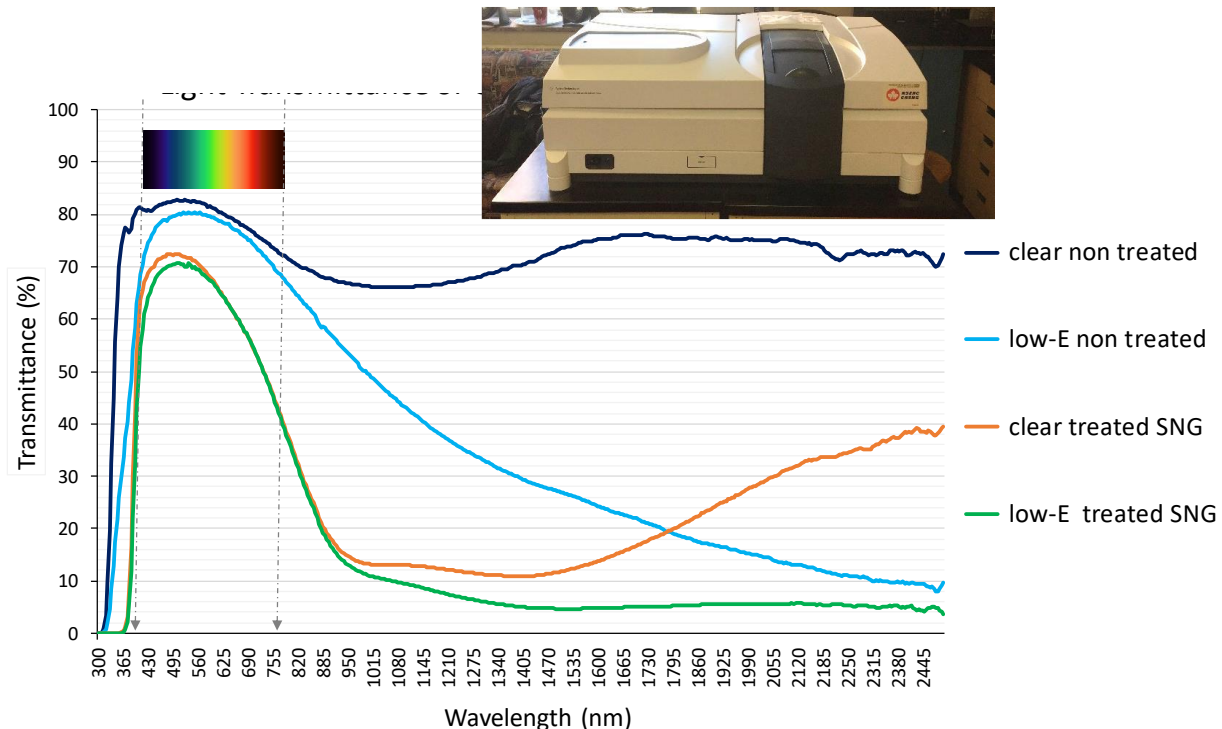
Smart selective window Nano-coatings



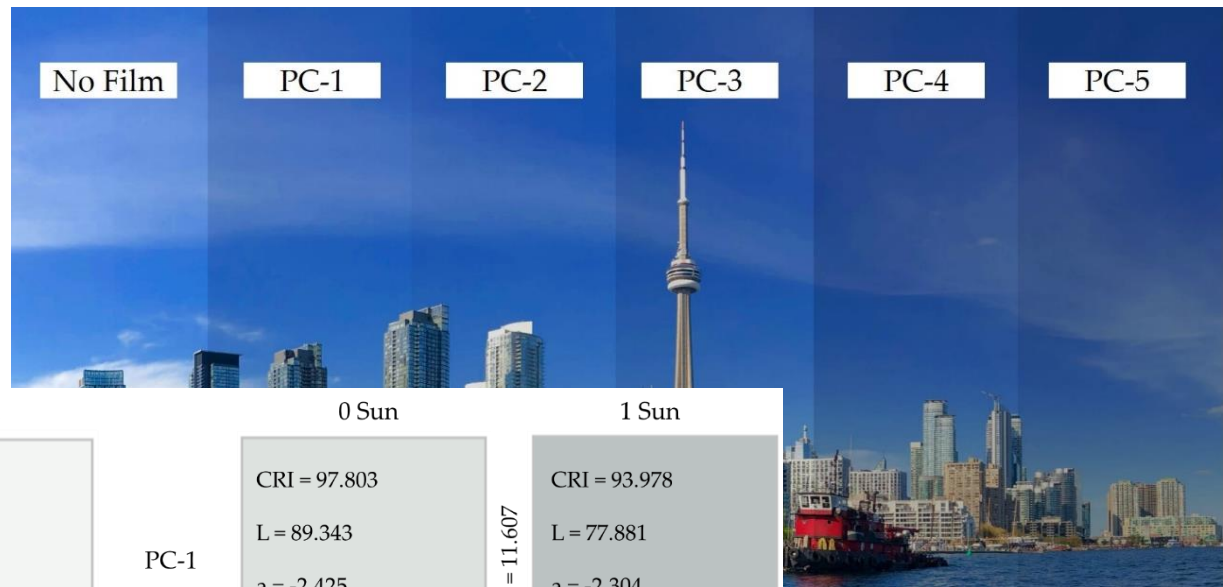
1 > A window optimized for daylighting and for reducing solar heat gains should transmit light in the visible portion of the spectrum only, while excluding heat gains from the near-infrared part of it.

New recent window coatings

- Composition: n-Butyl-acetate, Ethylene glycol monobutyl acetate, and 1-Methoxy-2-propanol acetate.
- The applied product was in the range of 25 grams of products per m^2 -- The thickness of the product was 8-10 microns, and hardened in 2 hours.



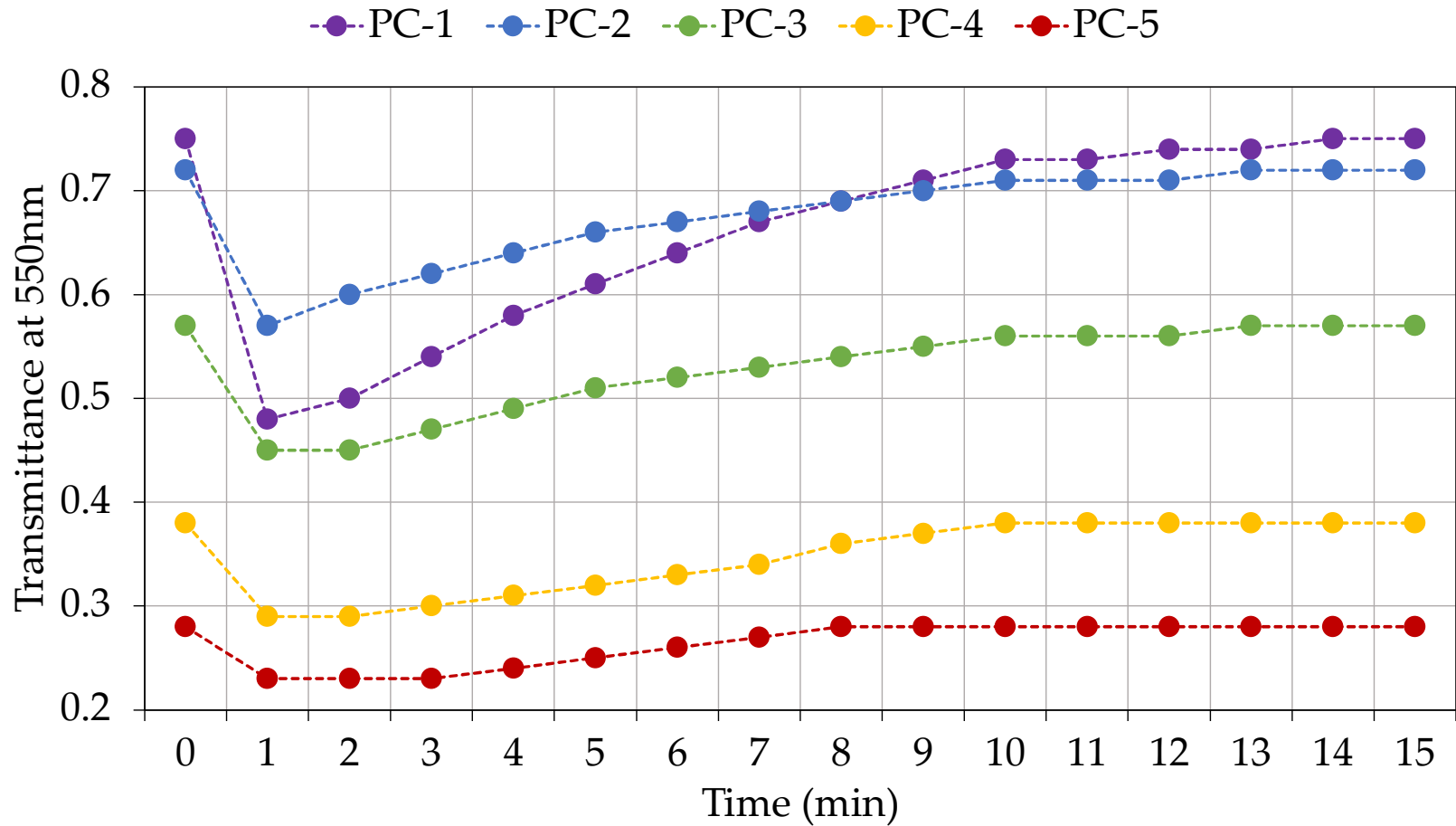
Flexible photochromic films



	0 Sun	1 Sun		0 Sun	1 Sun
Clear	CRI = 99.160 L = 96.013 a = -0.770 b = 0.256	$\Delta E = 0$ CRI = 99.160 L = 96.013 a = -0.770 b = 0.256	PC-1	CRI = 97.803 L = 89.343 a = -2.425 b = 0.881	$\Delta E = 11.607$ CRI = 93.978 L = 77.881 a = -2.304 b = -0.943
PC-2	CRI = 97.055 L = 88.461 a = -2.844 b = 1.210	$\Delta E = 7.172$ CRI = 97.430 L = 81.301 a = -2.999 b = 0.829	PC-3	CRI = 97.131 L = 79.845 a = -2.366 b = 0.434	$\Delta E = 5.461$ CRI = 97.741 L = 74.408 a = -2.658 b = 0.015
PC-4	CRI = 96.029 L = 67.608 a = -2.092 b = -1.734	$\Delta E = 5.528$ CRI = 96.897 L = 62.095 a = -2.332 b = -2.056	PC-5	CRI = 95.194 L = 60.628 a = -1.655 b = -2.379	$\Delta E = 5.506$ CRI = 95.326 L = 55.577 a = -1.848 b = -2.503

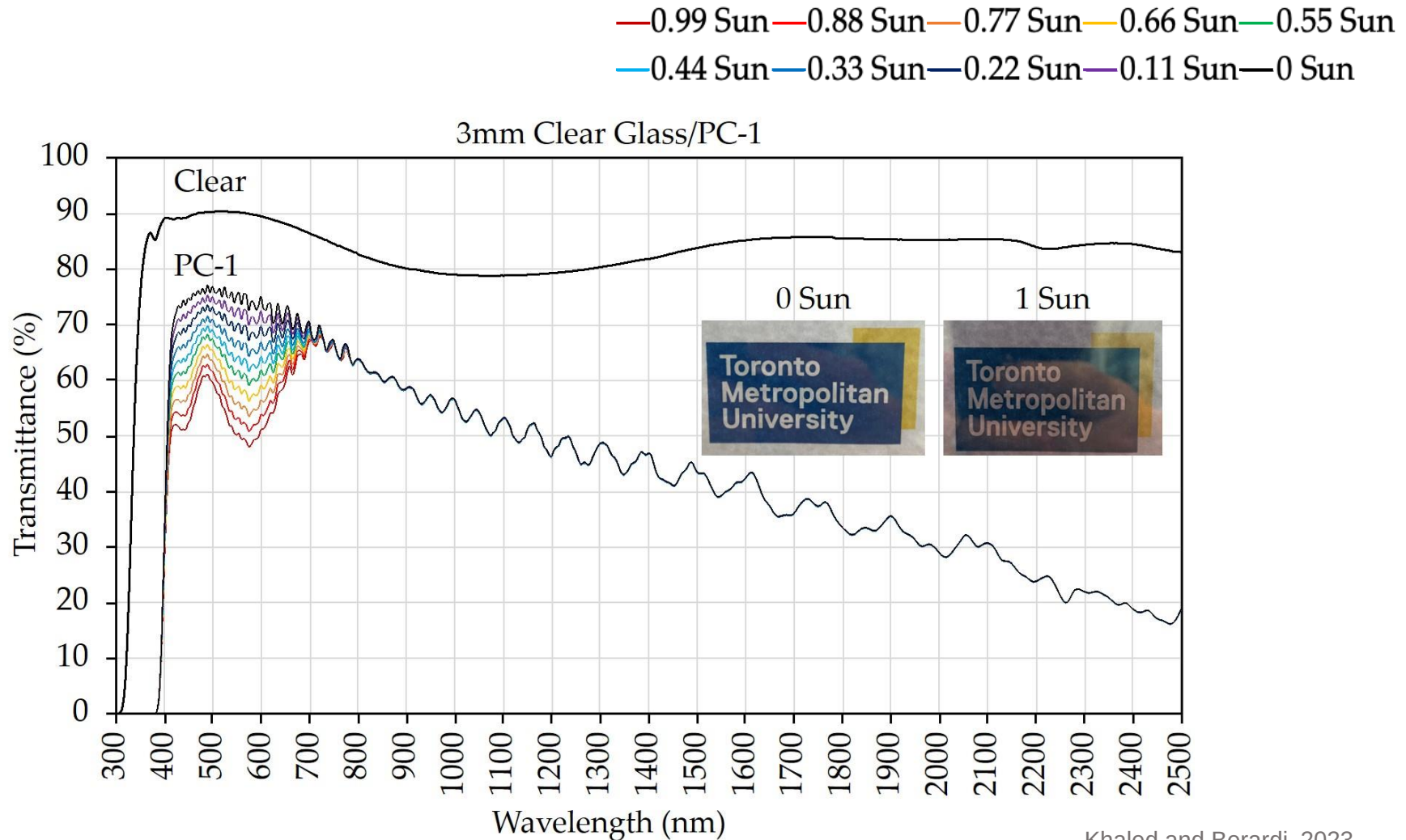
Khaled and Berardi, 2023

Flexible photochromic films



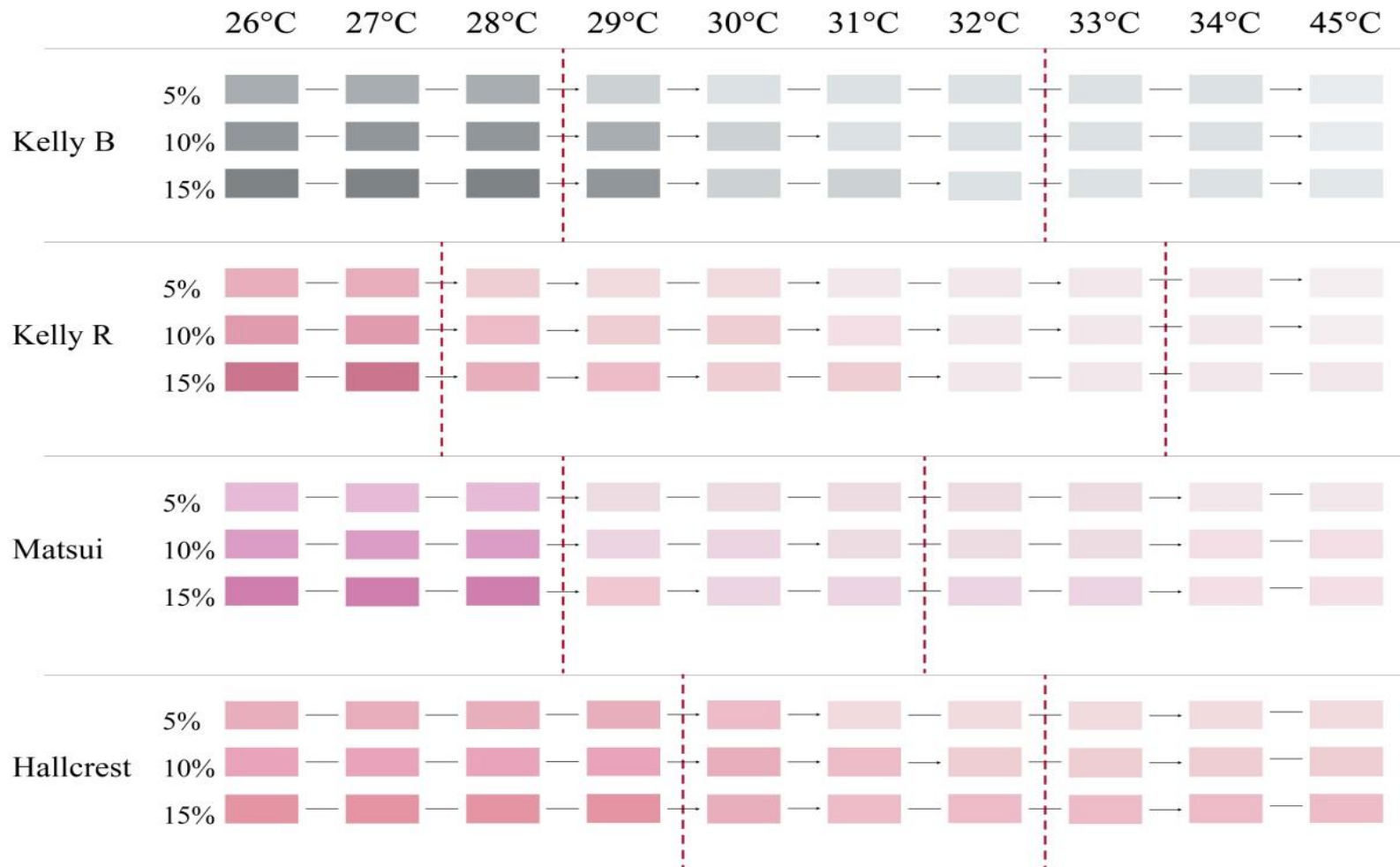
Khaled and Berardi, 2023

Flexible photochromic films



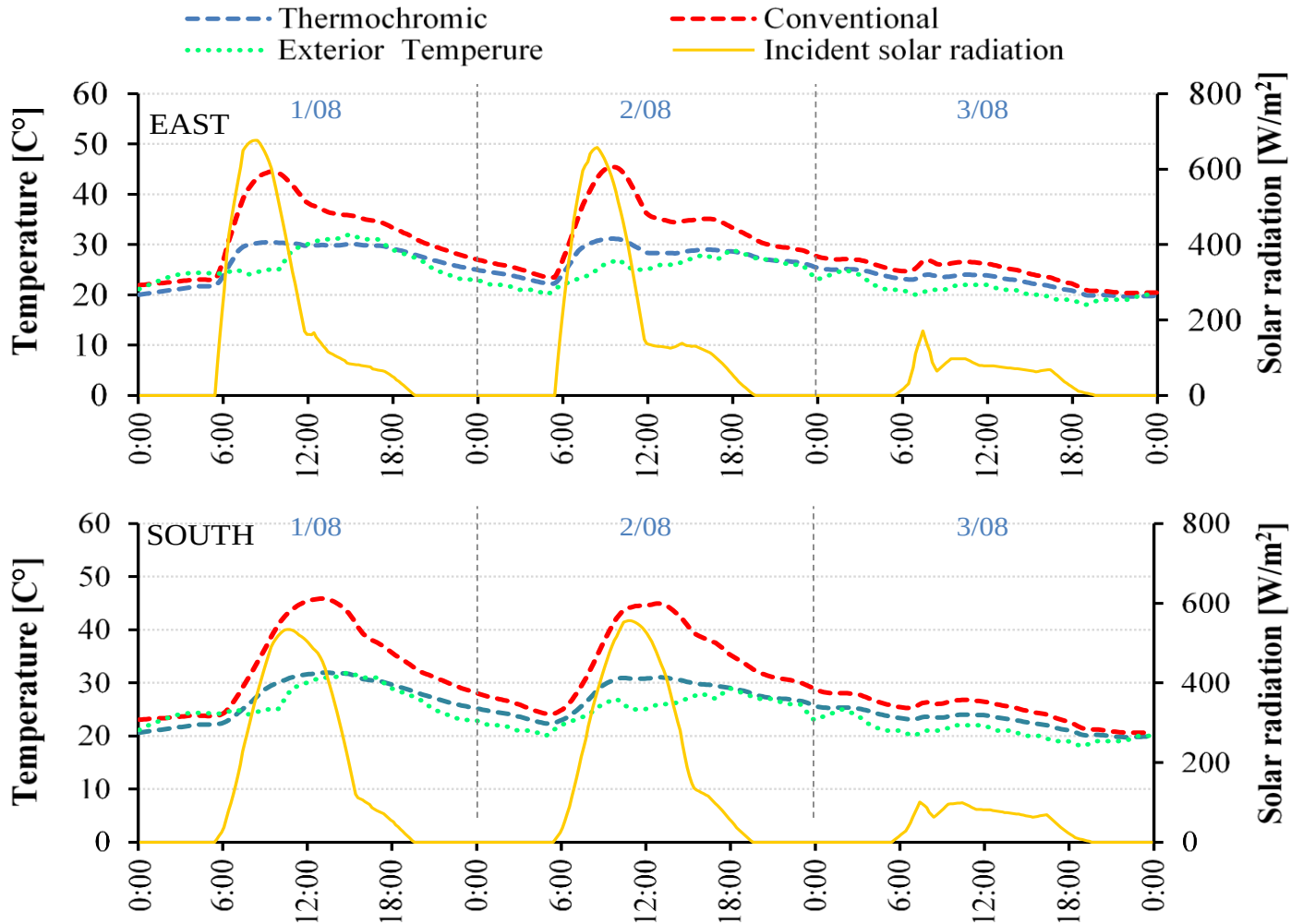
Khaled and Berardi, 2023

Thermocromic materials



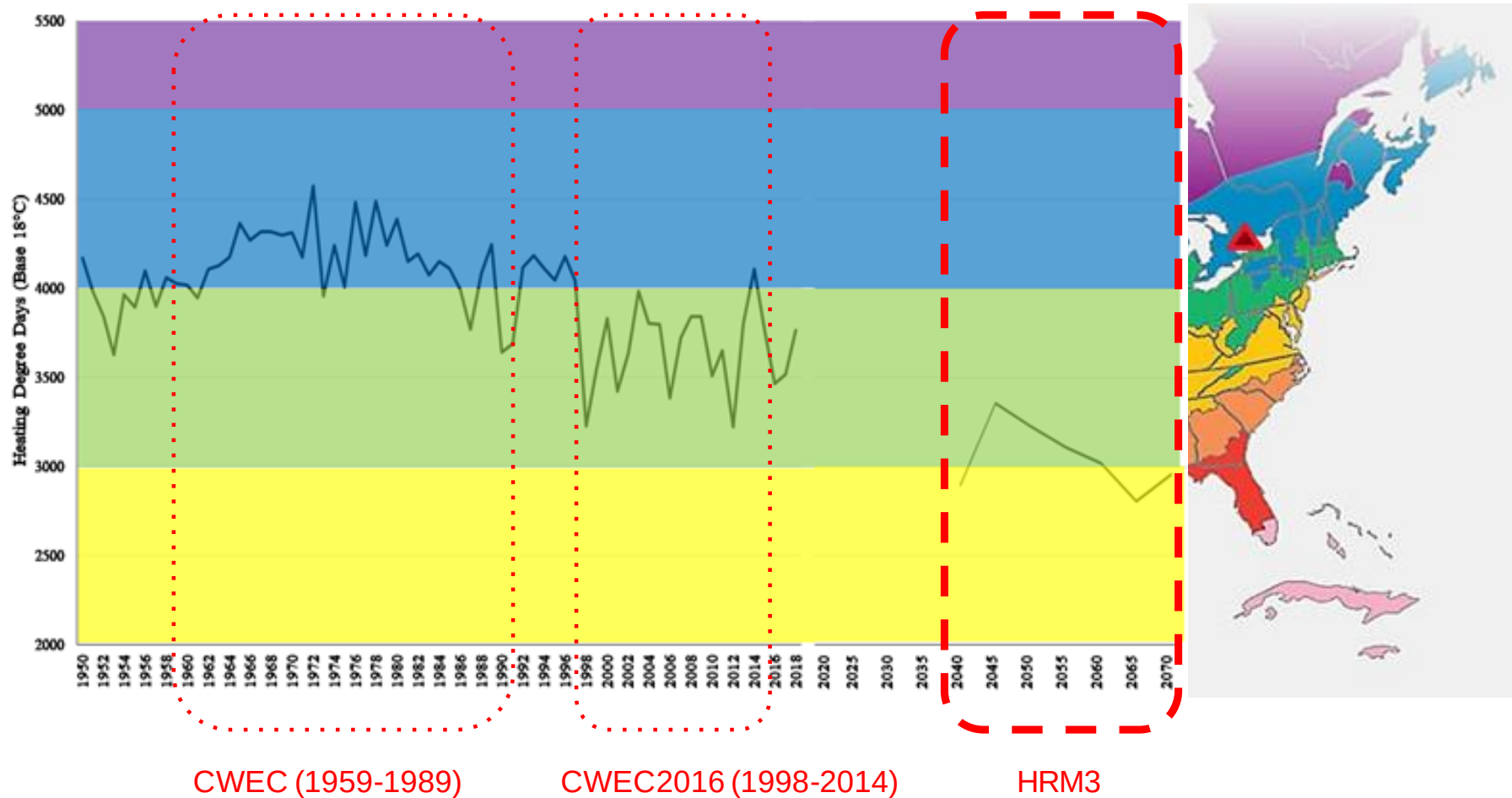
Berardi et al., 2020

Thermochromic materials

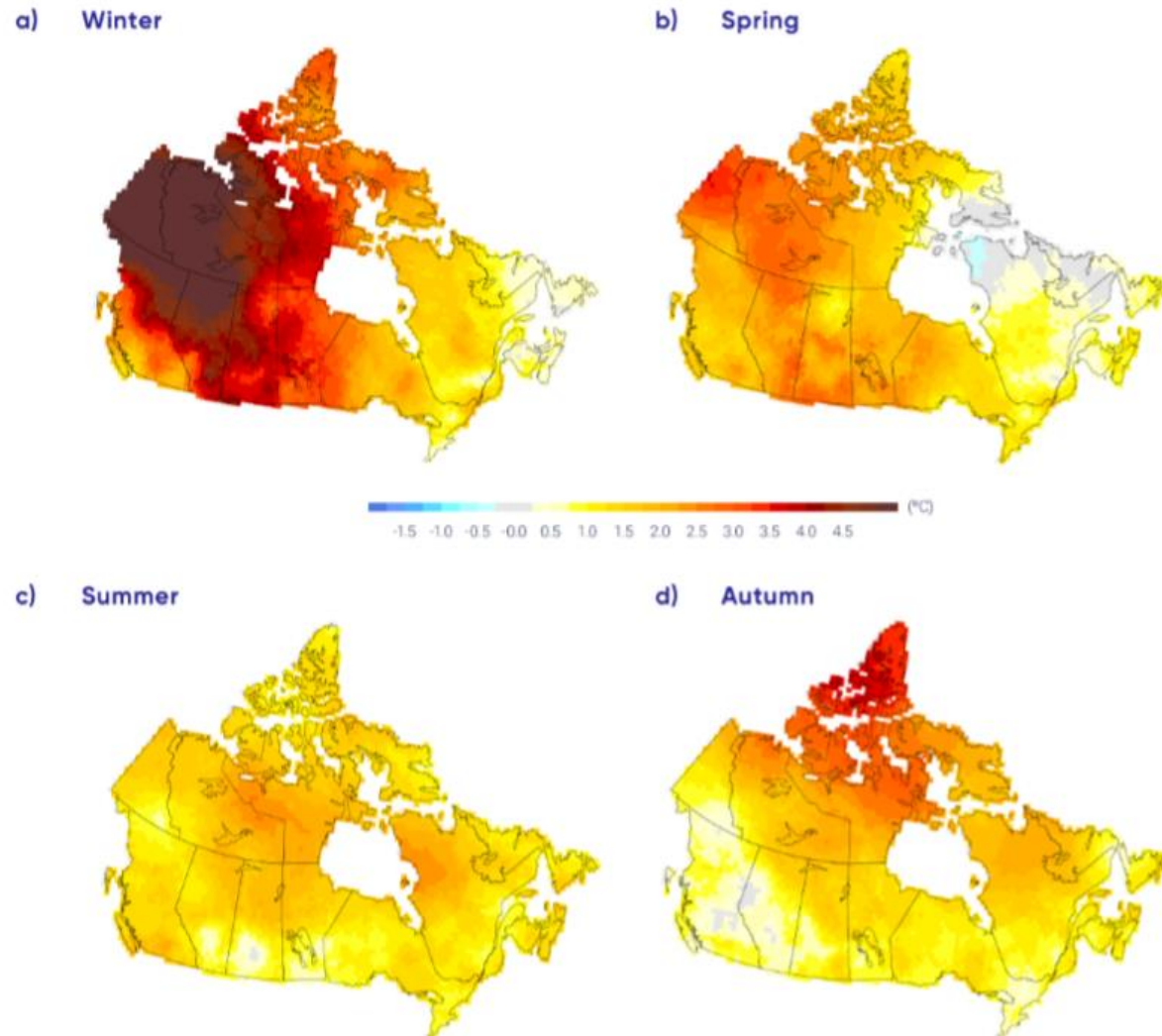


Berardi et al., 2020

New materials will need to consider Climate Changes



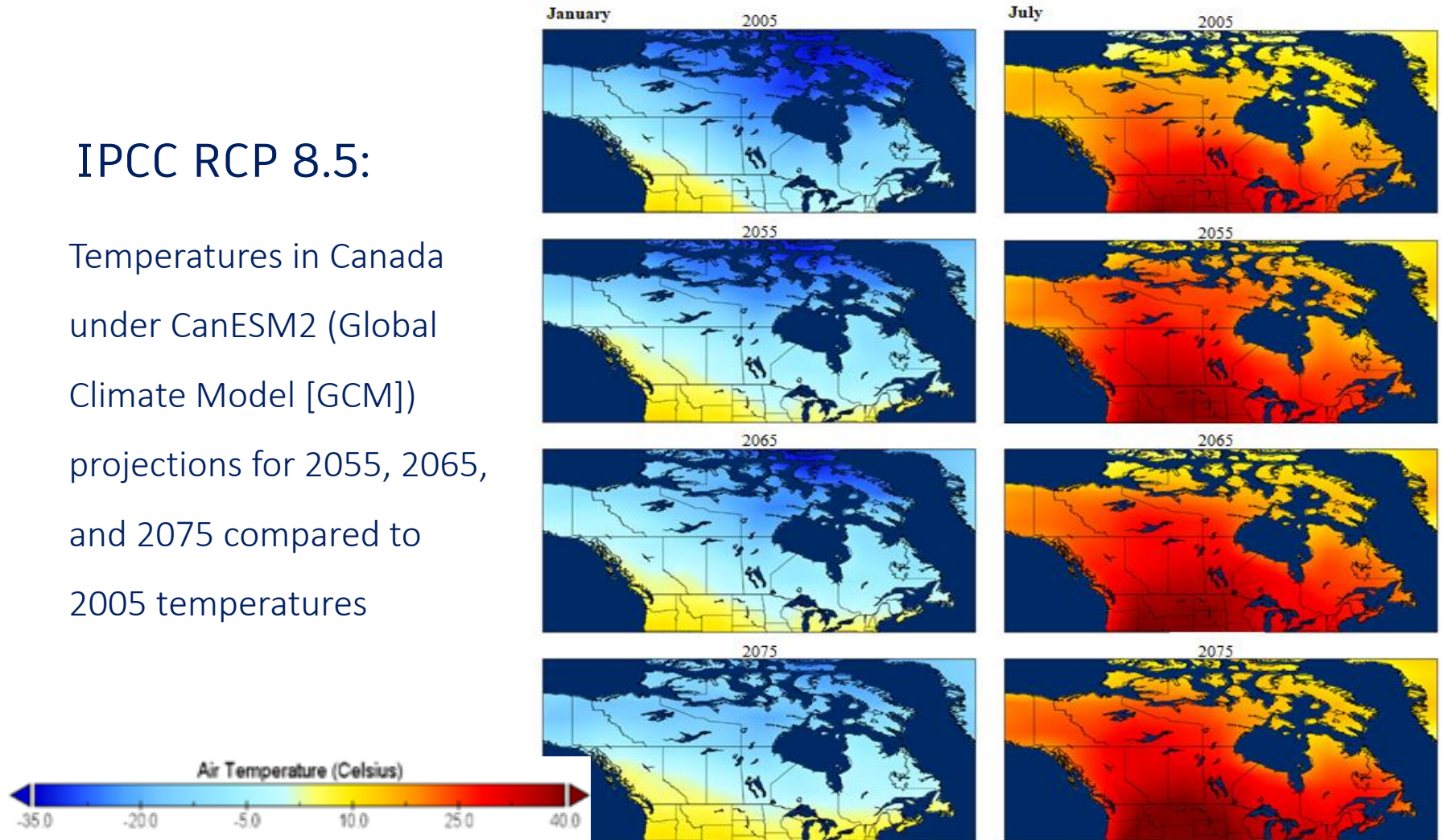
New materials will need to consider Climate Changes



New materials will need to consider Climate Changes

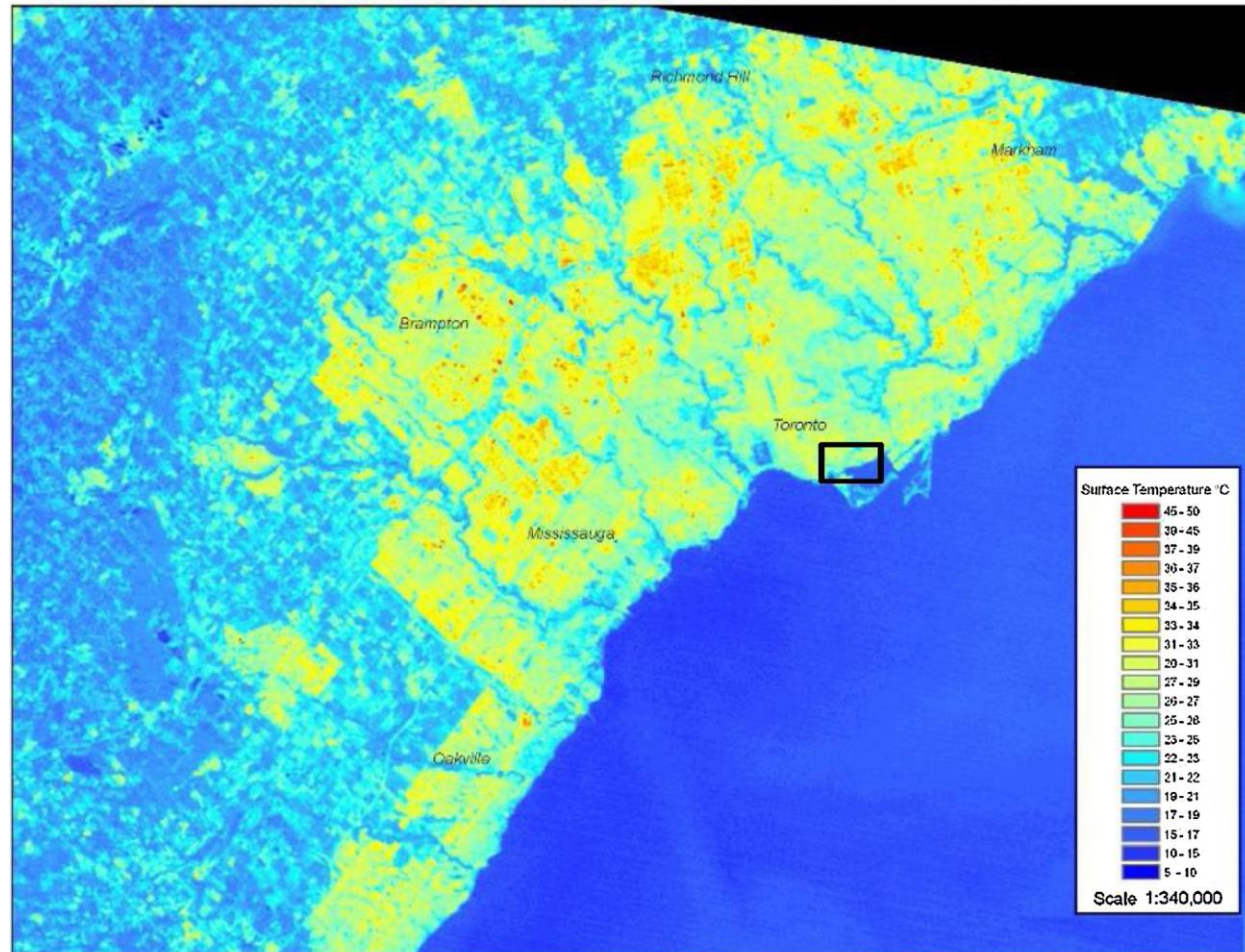
IPCC RCP 8.5:

Temperatures in Canada
under CanESM2 (Global
Climate Model [GCM])
projections for 2055, 2065,
and 2075 compared to
2005 temperatures



Synergic effects of Climate Changes & Urban Heat Island

Land Surface Temperatures - Greater Toronto Area - September 3, 2008

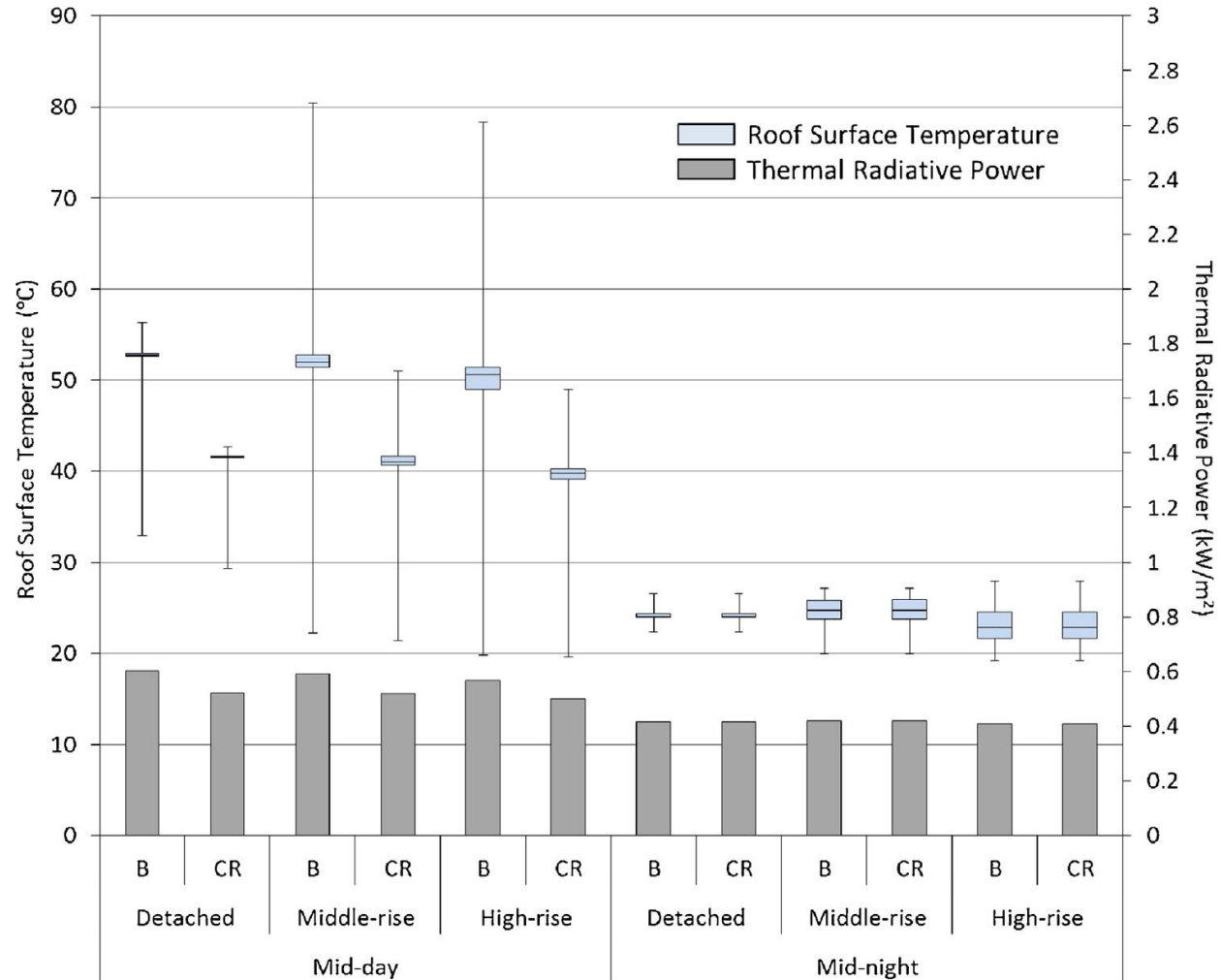


 Natural Resources
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Surface temperatures derived from Landsat TM imagery
Contact: Matthew Maloley, Natural Resources Canada

Example of Coating applications on roofs

UHI



Acknowledgments



Research sponsors



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25-27 July 2024 in **Toronto**. This IS THE official every 3-years event of the
IABP - International Association of Building Physics (IABP)

WWW.IBPC2024.ORG



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Important Dates:

July 1, 2023 > Abstract submission open

November 30, 2023 > Deadline for abstract submission

March 15, 2024 > Deadline for full paper submission

May 30, 2024 > Deadline for final revised paper submission



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