

3M Cooling Technologies for Buildings, Vehicles, and Outdoor Electronics

Passive Radiative Cooling *3M Energy Conservation Technologies for a Sustainable Climate*

*Saves Energy 24/7
Reduces Electricity Consumption
Reduces CO2 Emissions
Improves comfort and safety*

Tim Hebrink Bio

Passionate about Polymers & Sustainability

Education: BS ChemE, Univ of Minnesota

3M Career: 41 Years

2025-2026: Corporate Scientist, CRPL

2021-2024: Senior Staff Scientist, CRPL

2010-2021: Staff Scientist, CRPL

2008-2010: Lead Research Specialist , CRPL

2001-2008: Lead Research Specialist, DGFL

1995-2001: Senior Research Specialist, LMTC

1992-1995: Environmental Engineer, CRL

1990-1992: Product Development Engineer

1985-1990: Process Development Engineer

Internal Awards:

20 Discover Grants

18 Genesis Grants

6 Golden Step Awards

11 CTEI Awards

Corporate Process Engineering Award

2024 Carlton Society Inductee

External Awards:

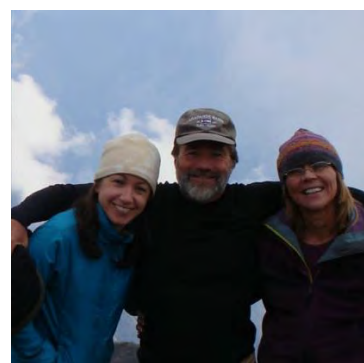
85 Issued US Patents (53 pending patent applications)

2010 Xcel Energy Renewable Development Fund

2013 MN Top Inventors Award for Material Science

2022 AIChE Sustainability Award

4 Department of Energy Awards



Personal Interests:

- Skiing
- Biking
- Hiking
- Kayaking



Family:

Wife – Kay

Daughter – Michelle

Son-in-Law: Phil

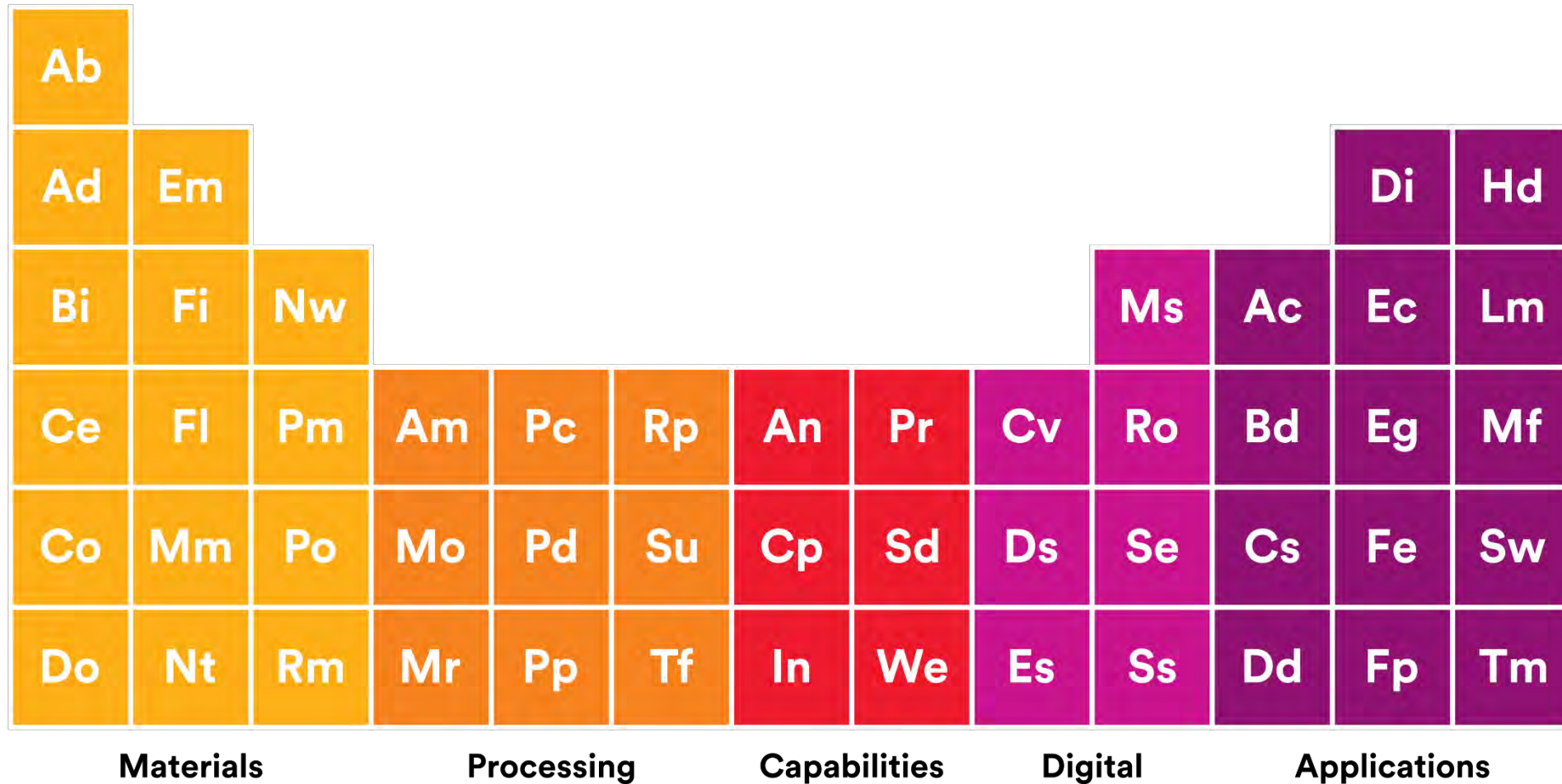
Grandsons: Miles, Leo

Fun Facts:

- Black Belt in Tak Kwon Do
- Climbed Mount Rainier and Mount McKinley
- Kayaked whitewater rivers in 7 countries



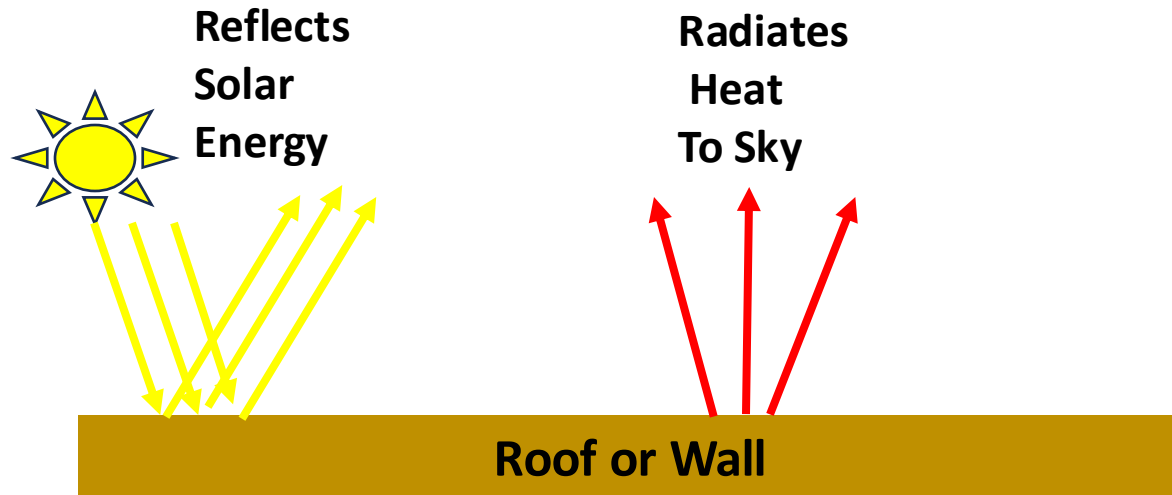
3M Technology Platforms



Successful New Product Growth Builds on Uncommon Connections

High Level Description of Passive Radiative Cooling

- **High Solar Reflectance** → minimizes heating of surfaces by Solar Absorption
- **High Thermal Emittance** → enables efficient radiation heat transfer from hot objects/surfaces to cold objects/surfaces
- **High Selective Emittance** → enables sub-ambient cooling during the day



Additional Important Properties

- **Long Outdoor Lifetime** → needs to be UV stable
- **Easy to clean** → maintains high solar reflectance

High Level Summary of 3M Cooling Technologies

3M Cool Roofing Granules

- Passive cooling of residential buildings
- Reduces electricity consumed for AC



3M™ Cool Roofing Granules are available in a range of color and solar reflectivity, enabling custom blends that will meet reflectivity targets while maintaining the curb appeal of consumers' homes.



- Enables cooler roofs with no change in appearance

3M Glass Bubbles

- Can be used in passive cooling paints/coatings
- Lightweight
- Insulation



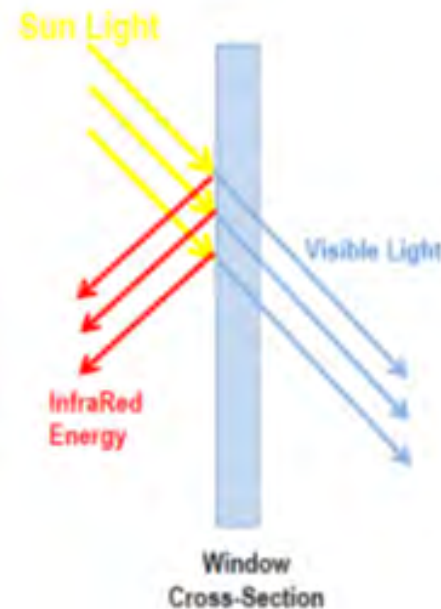
Exterior paints and coatings



Interior paints

3M Infrared Mirror Films

- Improves comfort
- Reduces electricity consumed for AC



3M™ Prestige Series Solar Films

3M Passive Radiative Cooling Film

- Improves comfort and safety
- Reduces electricity consumed for AC



- Reduces surface temperatures by 10-30C
- Comes with adhesive
- Easy to apply to flat and corrugated roofs
- >10year outdoor life
- Easy to clean

***developmental product**

Challenges

- Sustainable cooling solutions for the built urban environment to reduce the environmental and human health impacts of regional climate changes
- Rooftops comprise 20-25% of human-made surface area in Los Angeles, so focus is on cool roofs to reduce harmful Urban Heat Island effects.
- Cool Roofing can:
 - Reduce greenhouse gas emissions by up to 288 thousand metric tons of CO2 equivalent annually.
 - Lower a homeowner's utility bill 10-20% annually by cooling indoor air temperatures 3-12° F
 - Cool outdoor air temperatures by reflecting heat back to the atmosphere

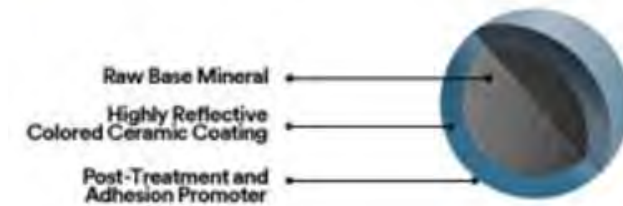
Audience

3M™ Cool Roofing Granules help roofing manufacturers design products to decrease urban temperatures for both low slope and steep slope roofing for commercial and residential markets.

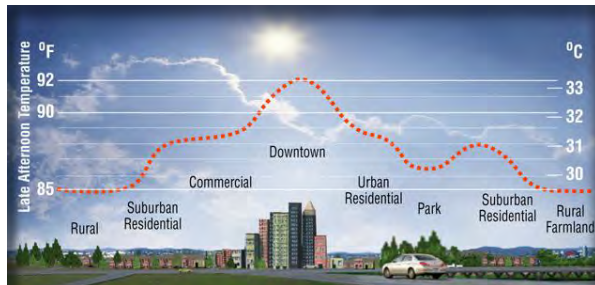
Differentiators

- 3M™ Cool Roofing Granules are available in a range of color and solar reflectivity, enabling custom blends that will meet reflectivity targets while maintaining the curb appeal of consumers' homes.
- 3M™ Cool Roofing Granules enable cooler roofs with no change in appearance/aesthetics of the roof

3M™ Cool Roofing Granules



Technologies



<https://heatisland.lbl.gov/>

3M Glass Bubble Applications: Construction Materials, Paints & Coatings

Whether your coating needs to withstand the elements or provide a pleasing finish, specialty fillers can help improve performance and potentially reduce resin demand.

3M™ Glass Bubbles can help:

- Sprayable thermal protective coatings
- Solar reflective paint
- Low-shrink spackling, caulks/sealant
- Lightweight polymer/wood composite
- Interior and exterior mortar, adhesives
- High build façade paints and plaster



Spotlight: Solar Reflective Paints & Coatings

- Reflect sunlight and help improve thermal insulation
- Help reduce energy costs by potentially lowering inside temperatures

Multi-Layer Optical Mirror Films... Inspired by nature

At every interface between two different refractive indices, some light is reflected, and some is transmitted (neglecting absorption). When layers of differing RI's alternate, there is a constructive interference for some wavelengths. Examples of this can be found in nature in butterfly wings and rainbow trout scales.

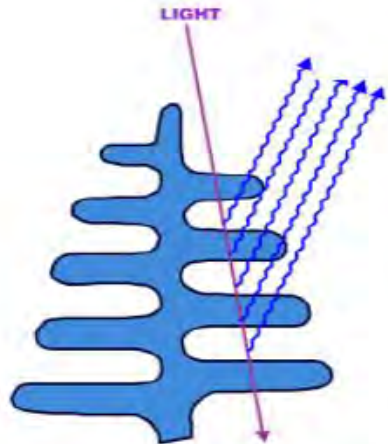
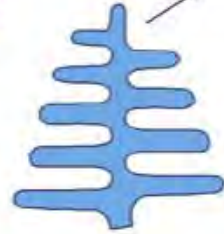
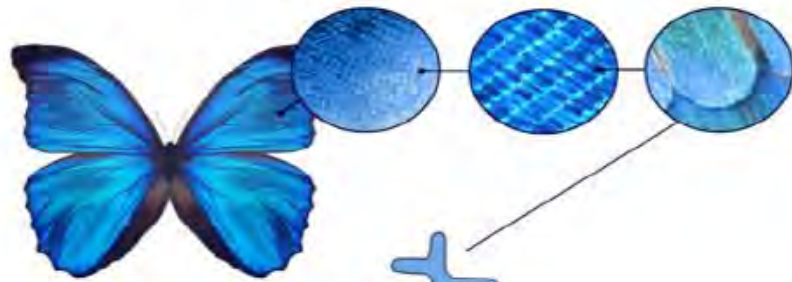


Diagram shows light entering and blue light reflecting off

Morpho butterfly multilayer structure

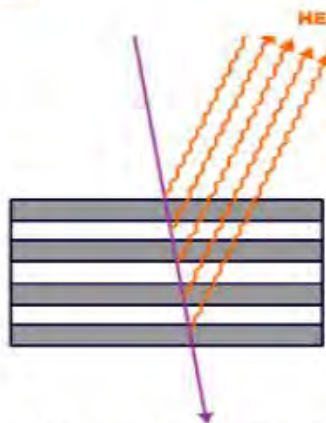
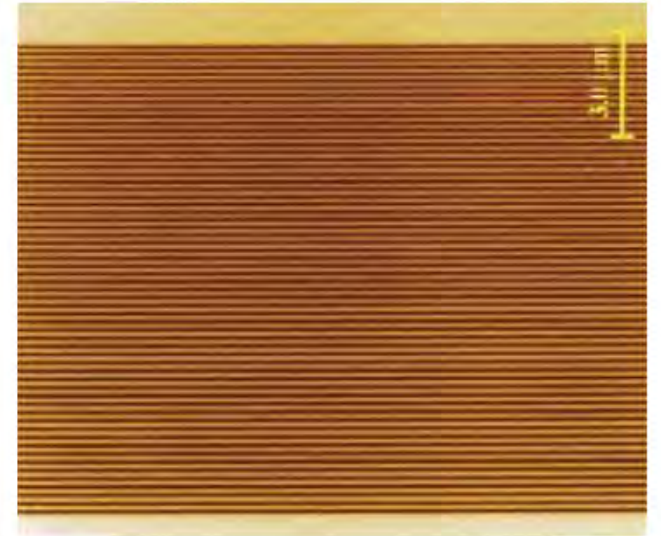


Diagram shows light entering and heat reflecting off

3M Prestige Window Film multilayer structure

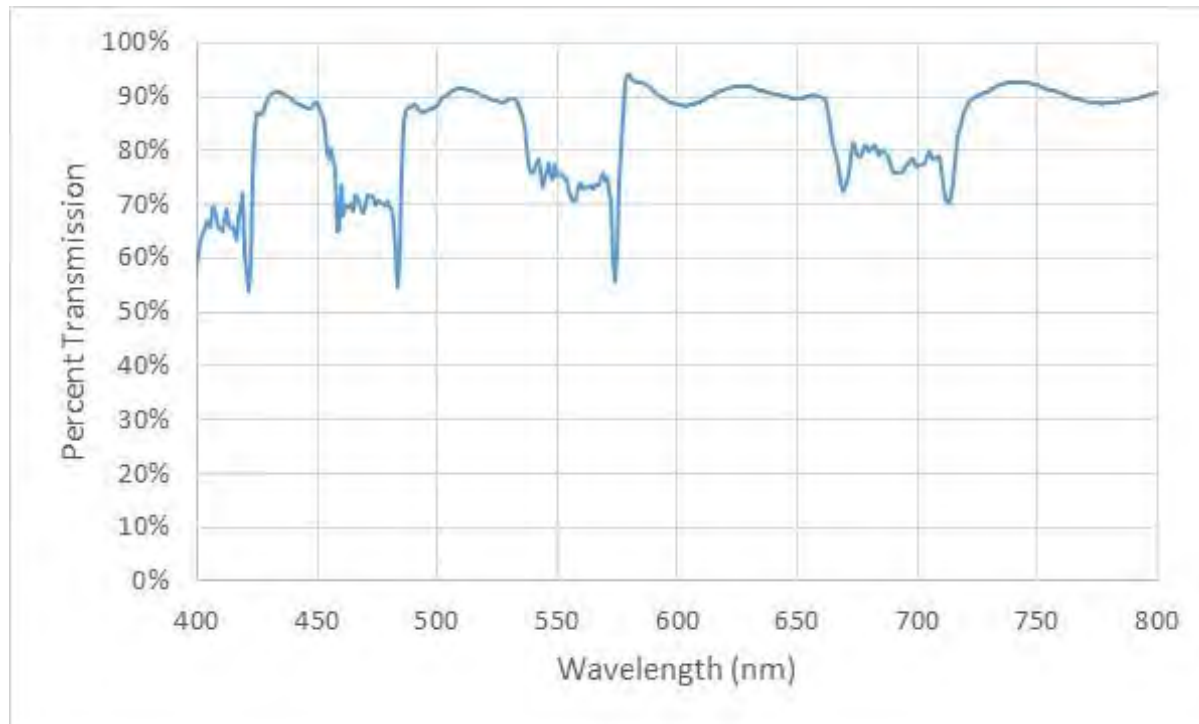
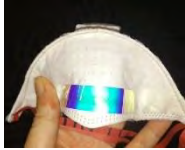
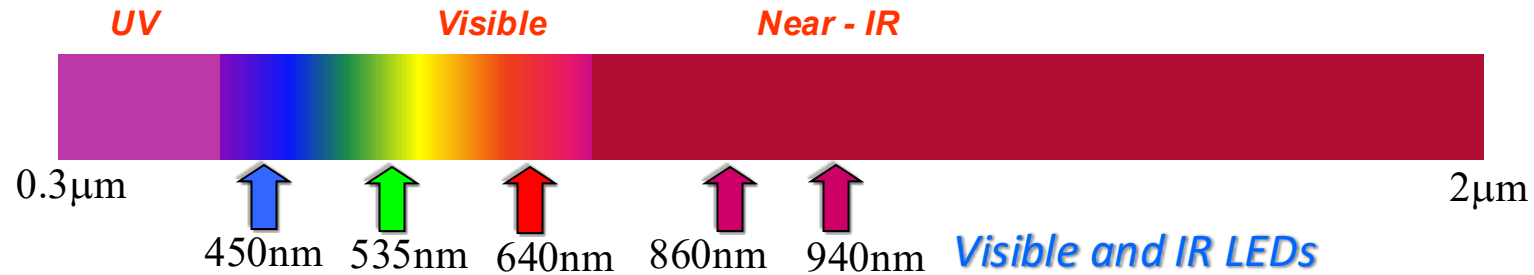


1/4 Wave Constructive Interference

- 100-1000 layers
- 15-200 nm thick
- Alternating layers of Bi-refringent and Isotropic polymer pairs
- Tunable reflection bands

Examples of MOF application

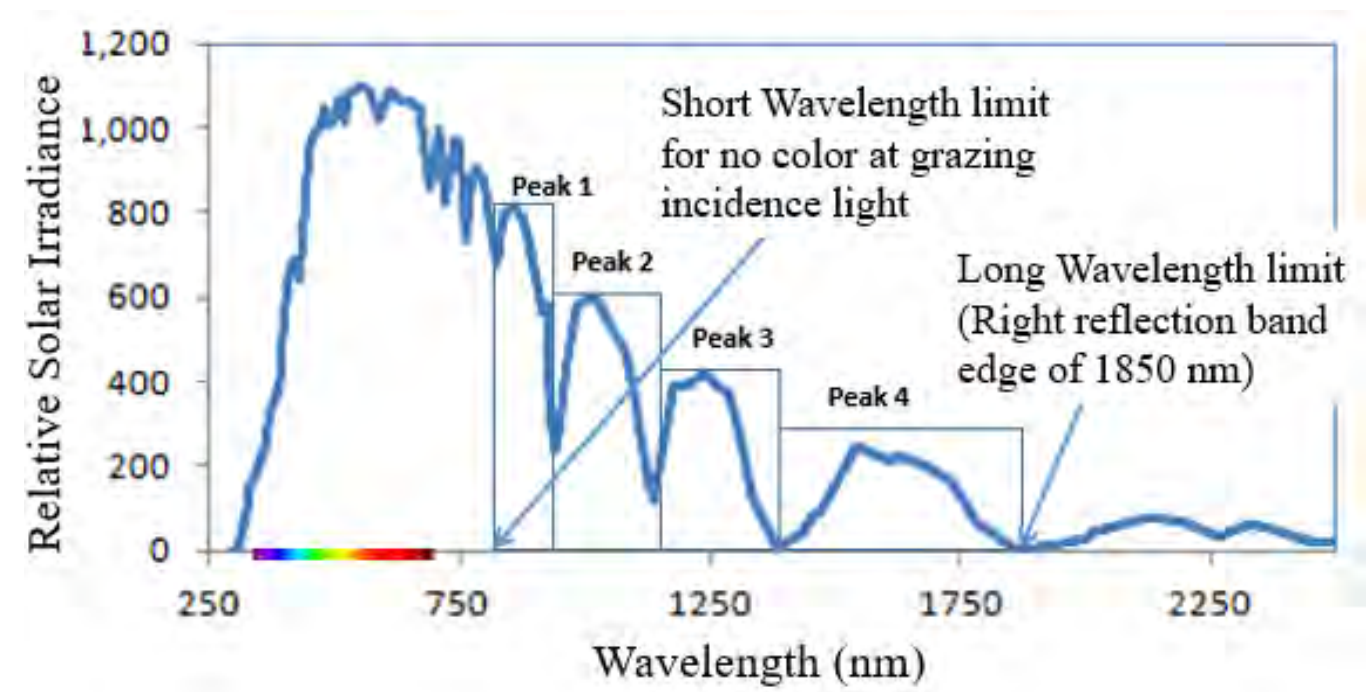
Tailored optical transform



- Broad design space
- Robust performance
- Low-cost at scale

Energy Saving Polymeric Films

Extended Band InfraRed Mirror Films reflects IR Peaks 3 and 4



	Short Wavelength (nm)	Long Wavelength (nm)	Total Solar Weight (%)
Peak 1	870	950	6.05
Peak 2	950	1140	11.47
Peak 3	1140	1375	9.18
Peak 4	1375	1850	8.63

- UCSF(Ultra Clear Solar Film) reflects ~25% of Total Solar Energy
- EBWF (Extended Band Window Film) reflects >45% of Total Solar Energy

Energy Saving Applications of Multilayer Optical Films

- Highly reflective mirrors ~99% reflectivity

- Tunable reflection bandwidth mirrors

- UV Mirror (350-400nm)
- VIS Mirror (400-800nm)
- Near IR Mirror (800-1600nm)
- UV/VIS/IR Mirror (350-1600nm)

- Reflective Polarizers

Liquid Crystal Displays



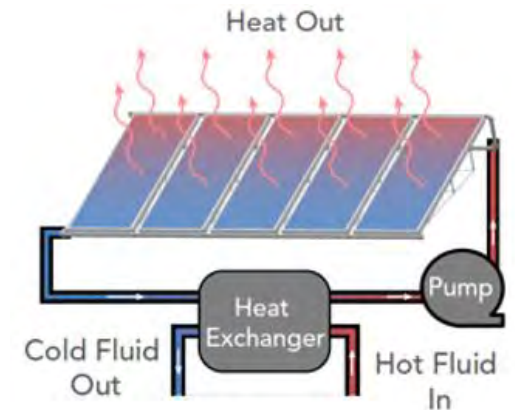
- Prevented 1-2 megaTons of CO2 emission per year
- Cumulative reduction of 30 megaTons over past 20 year



Transparent Solar Heat Rejection

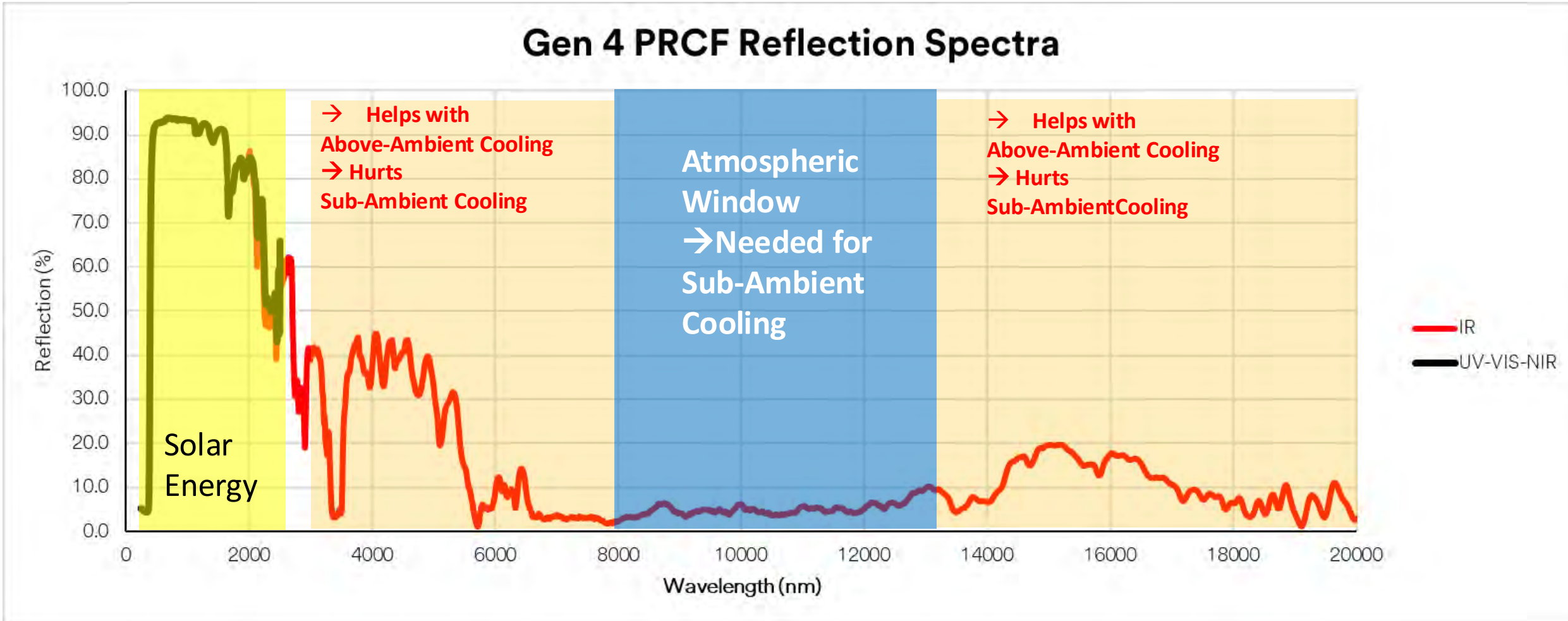
- Will extend EV driving range
- Reduces driving range anxiety

Radiative Cooling



Desired Radiative Properties of PRCF

- Reflects 0.4 - 2.5 microns
- Absorbs 8.0 - 13.0 microns (100 - %Reflection)



- ***Kirchoff's law tells us that Emissivity is equivalent to Absorptivity***
- ***When there is no light Transmission, %Absorption = 100 - %Reflection***

Passive Radiative Cooling Film on Park Shelter (Ramada) Roof

Project in partnership with ASU on Phoenix City park shelter

*Images and data provided by Prof. David Sailor of ASU

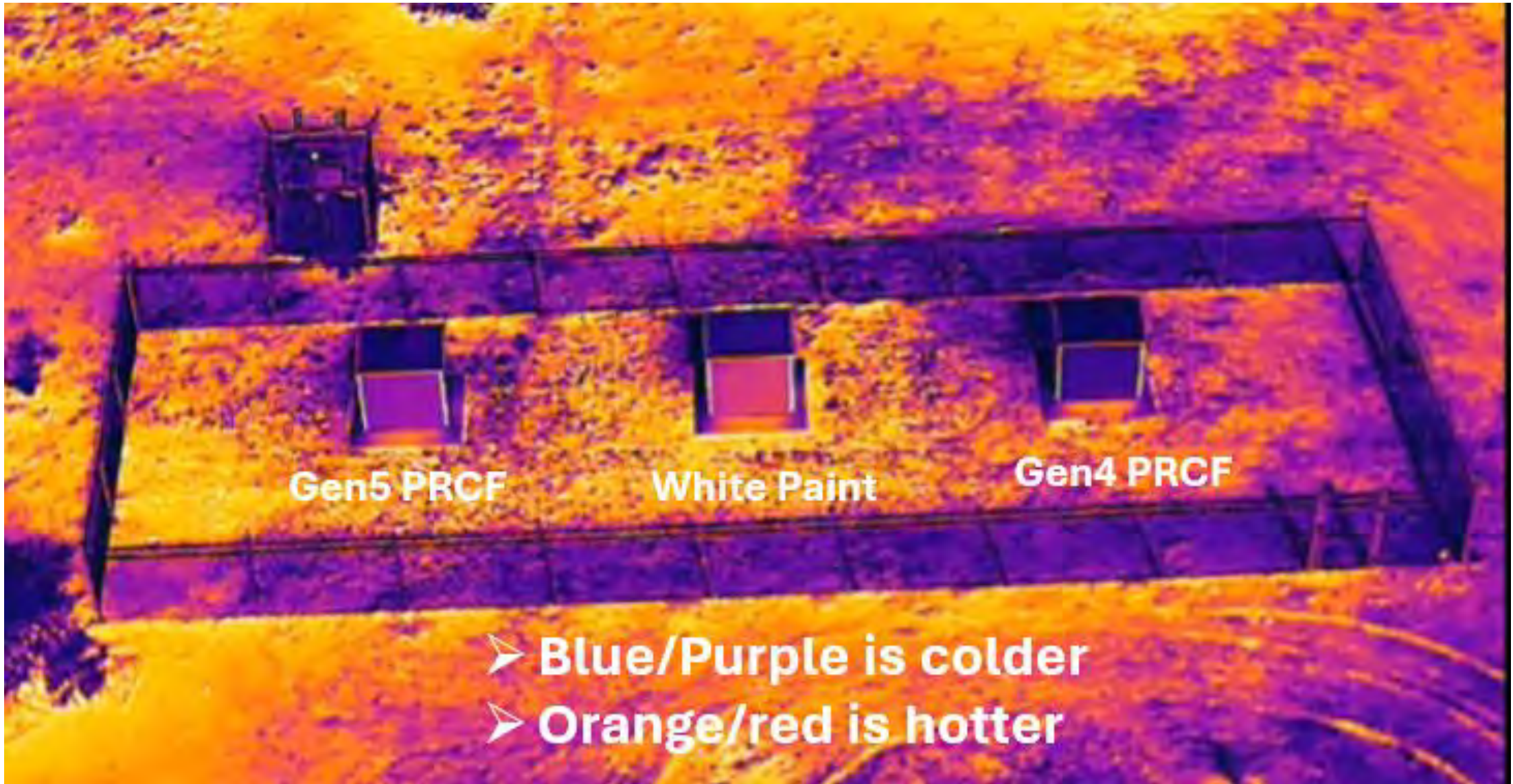


Passive Cooling Film on steel roof is 20-30F cooler than original painted steel roof.

Passive Cooling Film is cooler than surrounding environment and has a net cooling effect on ambient air.

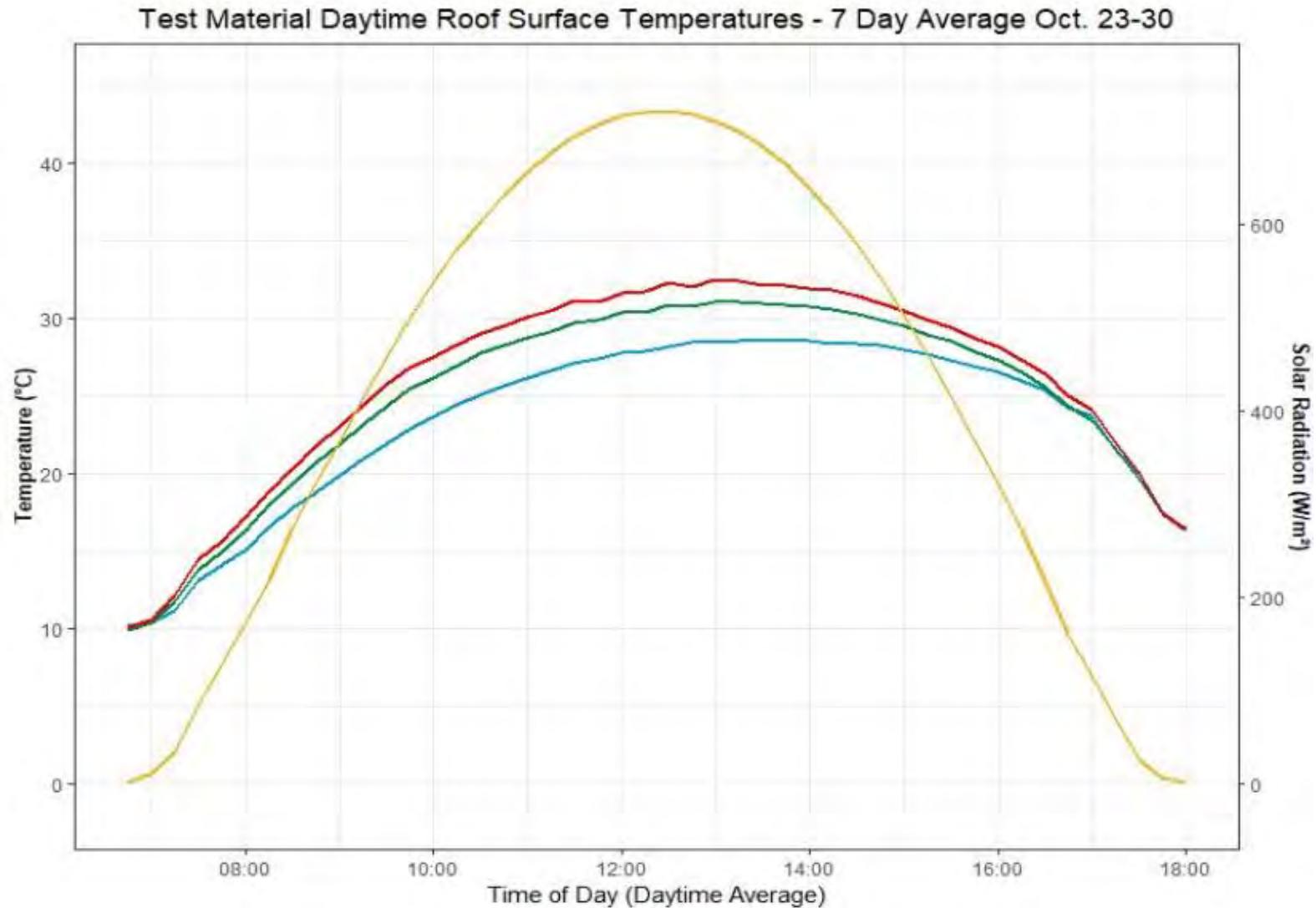
Passive Radiative Cooling Film on Small Shed Walls at ASU West Campus

Project in partnership with ASU Prof. David Sailor



Passive Radiative Cooling Film on Small Shed Walls at ASU West Campus

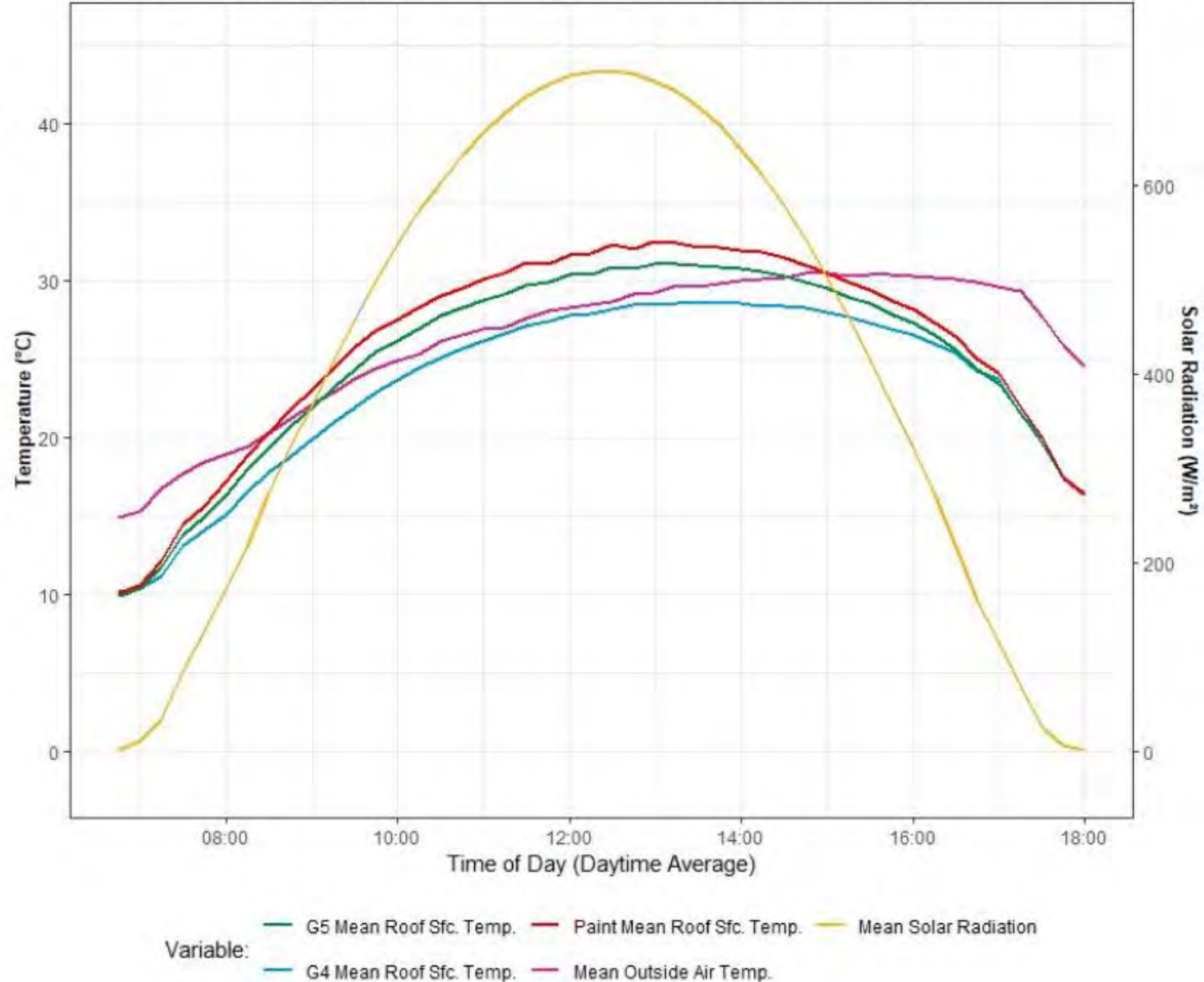
Project in partnership with ASU Prof. David Sailor



Passive Radiative Cooling Film on Small Shed Walls at ASU West Campus

Project in partnership with ASU Prof. David Sailor

Test Material Daytime Roof Surface Temperatures - 7 Day Average Oct. 23-30



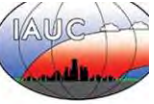
Passive Radiative Cooling publications in partnership with ASU

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journal homepage: www.elsevier.com/locate/buildenv



Highly reflective and thermally emissive urban infrastructure surfaces as radiant heat pumps for urban cooling

David Sailor*, Gina Fagliarone, Ariane Middel and Richard King—Arizona State University
Tim Hebrink—3M

11th International Conference on Urban Climate (ICUC-11)
Sydney AUSTRALIA

28 Aug - 1 Sept 2023

Conclusions

During a summer day...

- the conventional roof surface **warms the airshed by 185 W/m²**, while a radiative cooling surface can actually **cool the airshed by 18 W/m²**
- pedestrians under the radiant cooling shelter will see a **reduction of Mean Radiant Temperature by about 4.5 °C**
- the radiant roof **rejects twice as much radiation (LW+S)** out to space as the conventional roof.

Field evaluation of the efficacy of passive radiative cooling infrastructure: A case study in Phoenix Arizona

David J. Sailor^{a,*,b}, Gina Fagliarone^{b,c}, Tim Hebrink^d, Deepak Amaripadath^{a,b}

^a School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ, USA

^b Urban Climate Research Center, Arizona State University, Tempe, AZ, USA

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Keywords:

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UHI mitigation
Cooling film
Shade structures
Demonstration projects

ABSTRACT

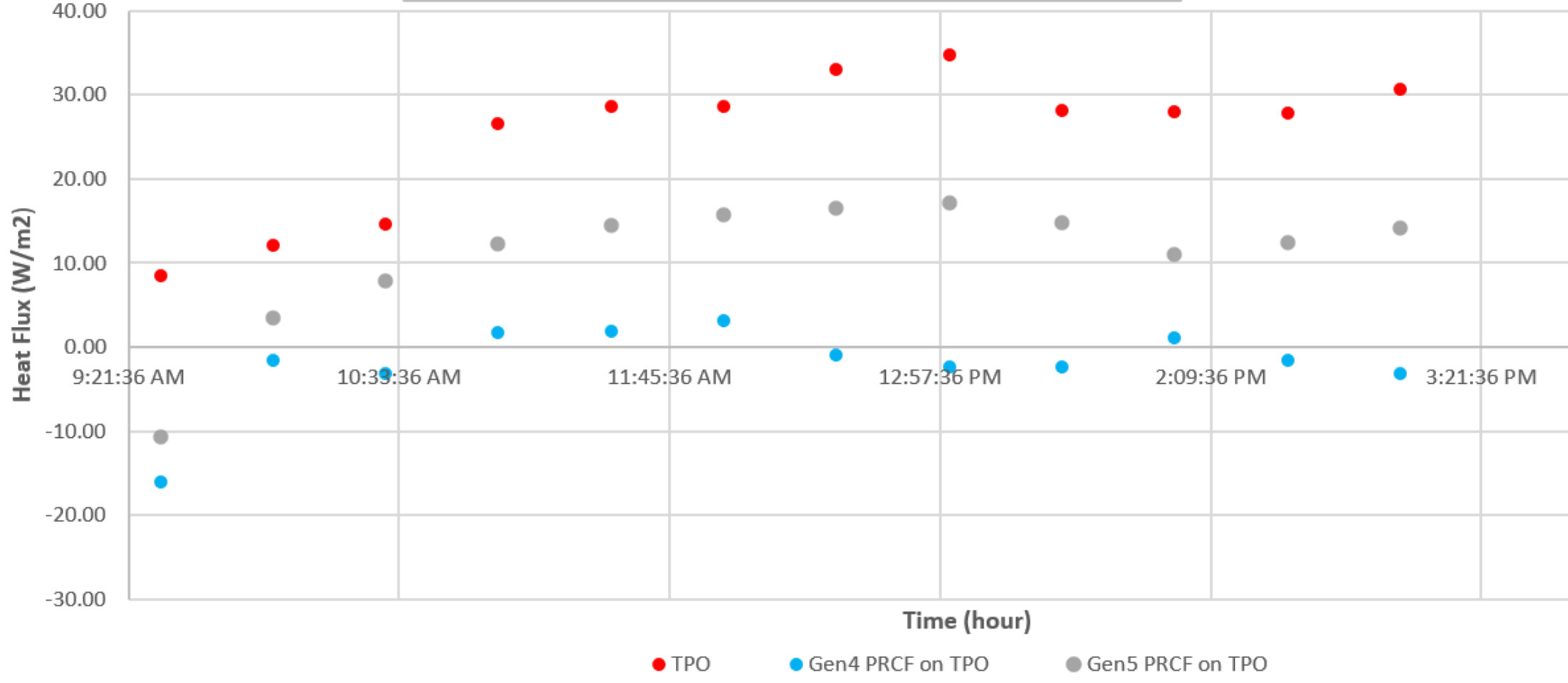
Radiative properties of shade structures affect their surface temperatures, sensible heat fluxes and longwave and shortwave radiation exchange. In fact, structures with high solar reflectance and thermal emittance have the potential to remain below ambient air temperatures, convecting sensible heat from the air to the surface and then radiating that heat to space—a sort of radiant heat pump.

We explore cooling benefits of urban surfaces with high solar reflectance and high thermal emittance radiative cooling films through a field measurement campaign in Phoenix Arizona, USA. The tested films have solar reflectance and selective thermal emittance (in wavelengths 8–13 μm) close to 95 %. We applied films in both before-after and control-test experimental designs on thin metal roofs of park shade structures. We measured surface temperatures, surface heat fluxes, upward- and downward-welling longwave and shortwave radiation, and local weather conditions.

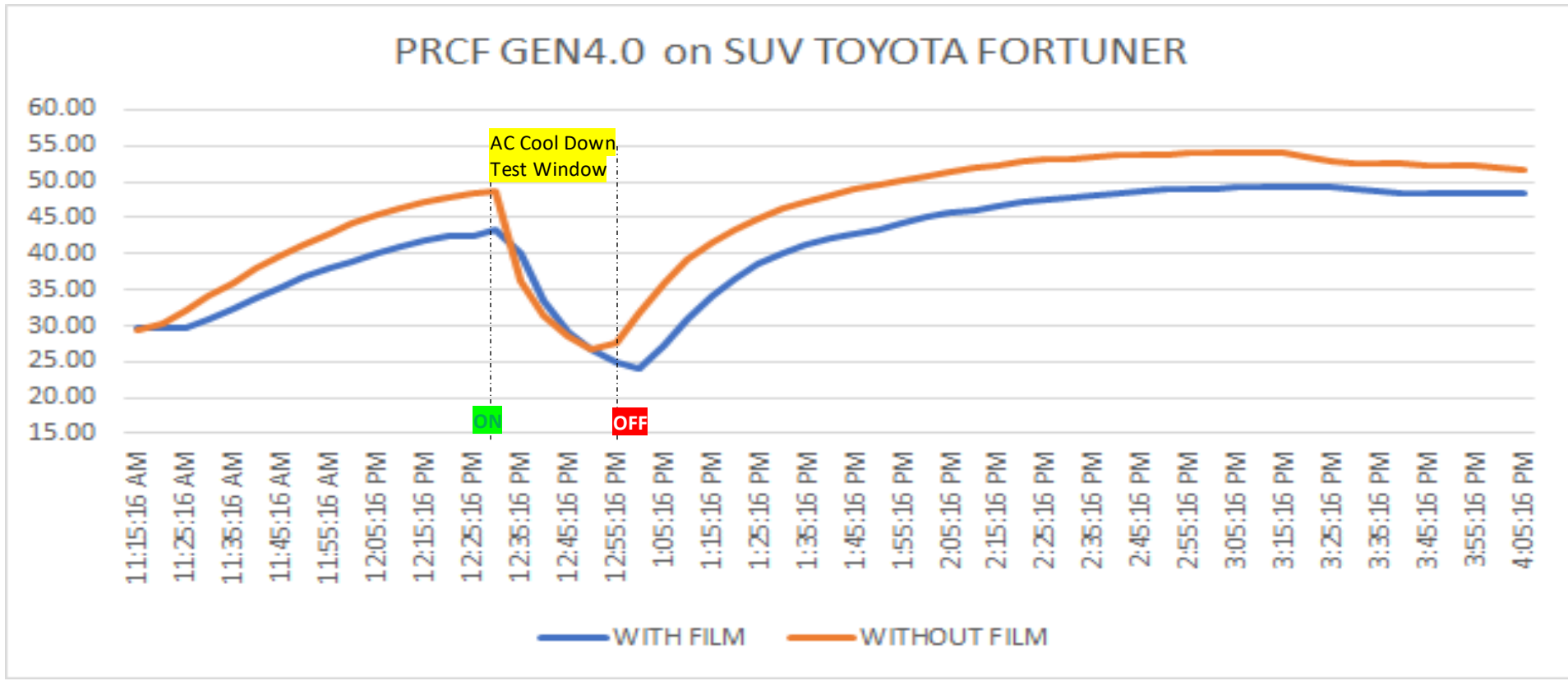
Results demonstrate the ability of radiant cooling films to reduce surface temperatures on hot days below ambient air temperatures. Test surfaces with cooling films were an average of 7 °C cooler than control shelter surfaces over the diurnal cycle, reducing sensible heat fluxes into the environment by up to 80 %, and lowering mean radiant temperatures for pedestrians using the shelters by more than 3 °C. It was also observed that the sum of the net reflected shortwave and emitted longwave radiation over the diurnal cycle can exceed the total incident longwave and shortwave radiation on the surface, demonstrating the ability of these materials to radiatively “pump” heat out of the city.

Solar Absorption Heat Flux comparison of Gen4 PRCF to Gen5 PRCF to TPO membrane

* negative number indicates heat flowing to Sky
 * positive number indicates heating due to solar energy absorbed
 * Heat flux impacted by clouds, firesmoke, and wind



Improved comfort measured with PRCF on white painted SUV



Location : Bangalore, Electronic City, South India
Date of Experiments : 3rd April 2024

➤ *Interior Air temperature reduction of 5C*

Improved comfort measured with PRCF on white painted delivery truck

Location : Bangalore, Electronic City
South India

Date of Experiments : 6th to 8th Feb



Cabin Temperature :

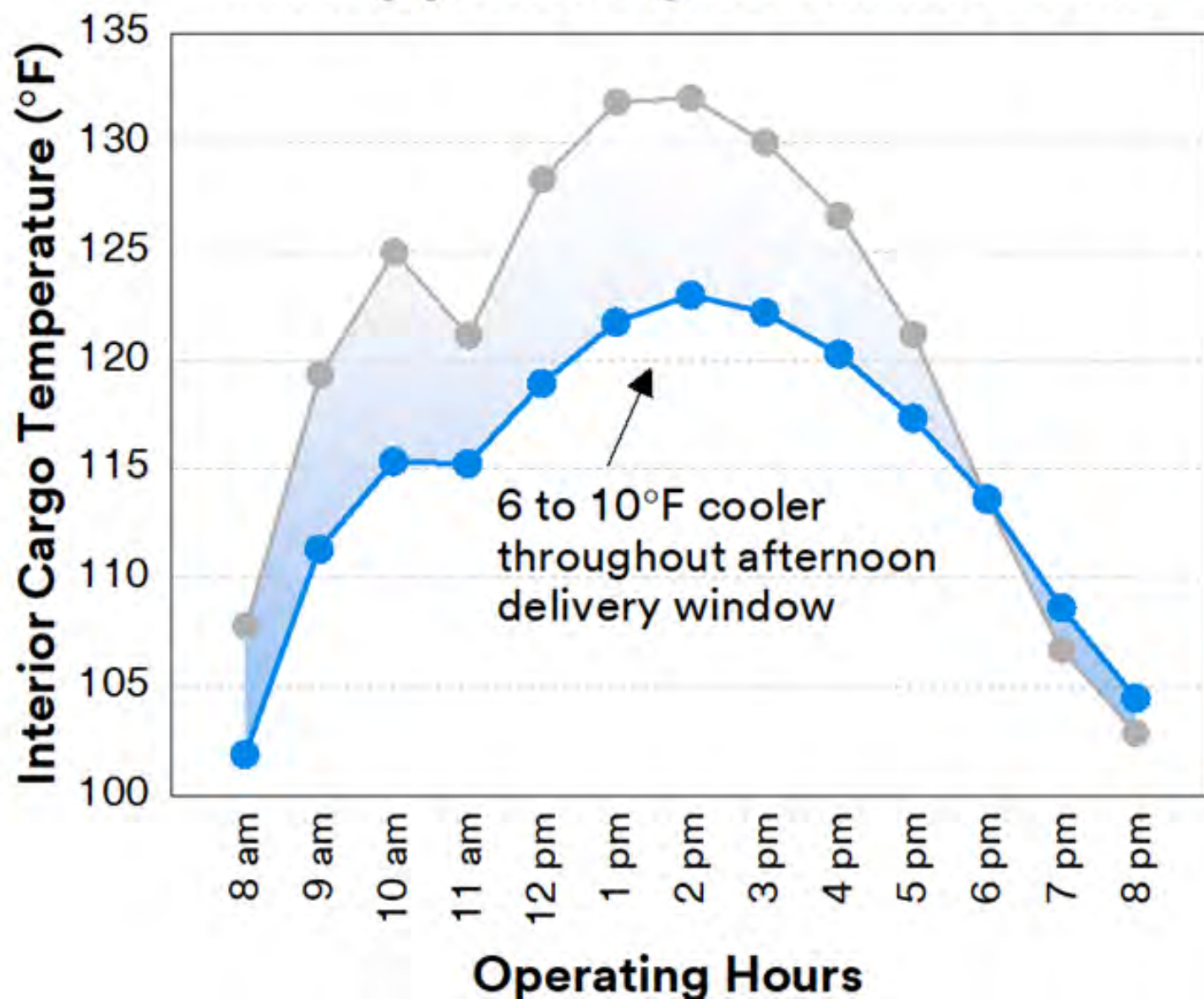
With film= 32.8 C

Without film = 38.8 C

Conditions: The cabin compartment was isolated and front windshield covered with sun protective reflector sheet.

** Insulating divider placed between two halves of truck cabin*

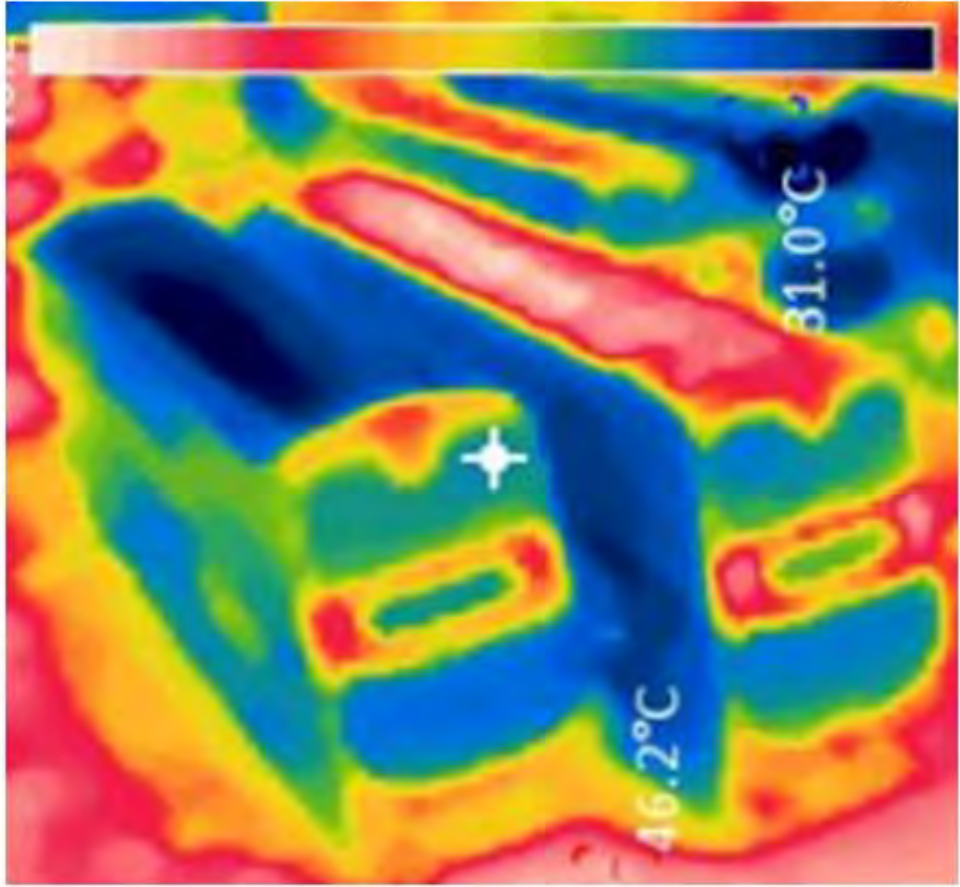
Cooling Film kept cargo areas cooler during peak August summer heat



Inside air temperature 5C cooler with PRCF on KMB bus in Hong Kong

*testing was conducted in October which is not the hottest time of year

Gen4 PRCF on the left No PRCF on the right

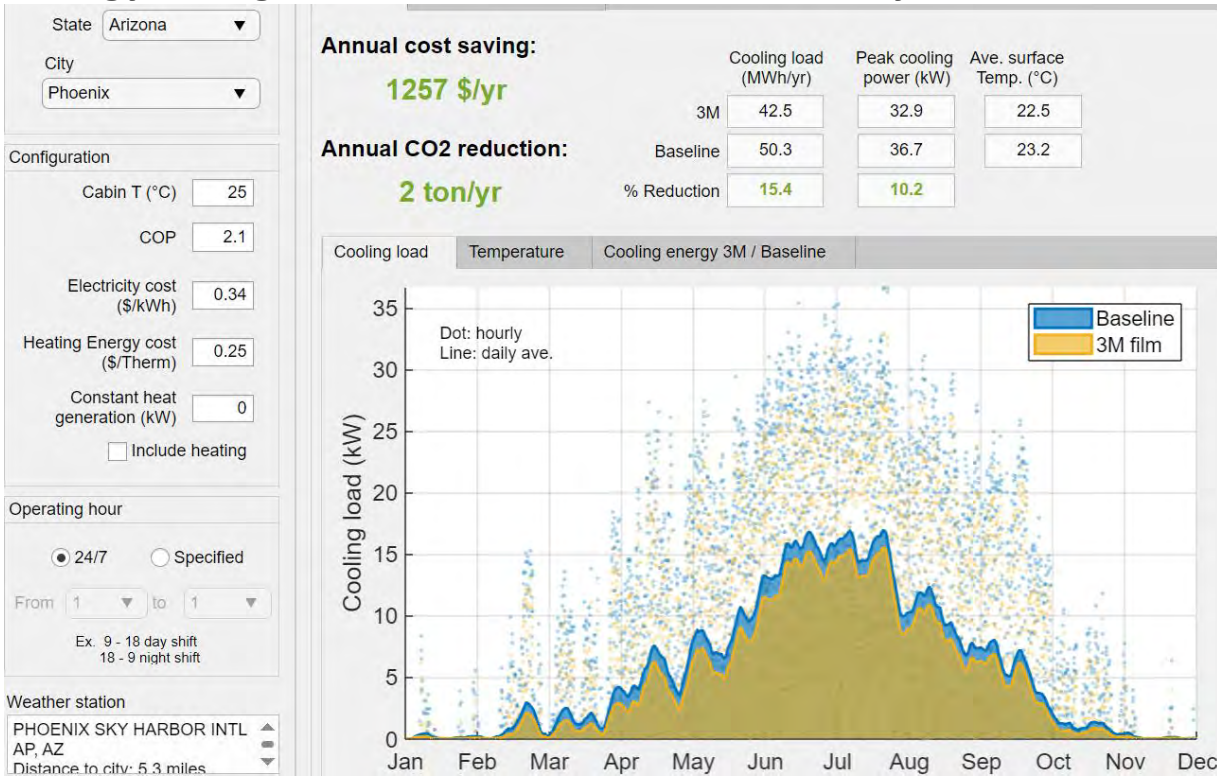


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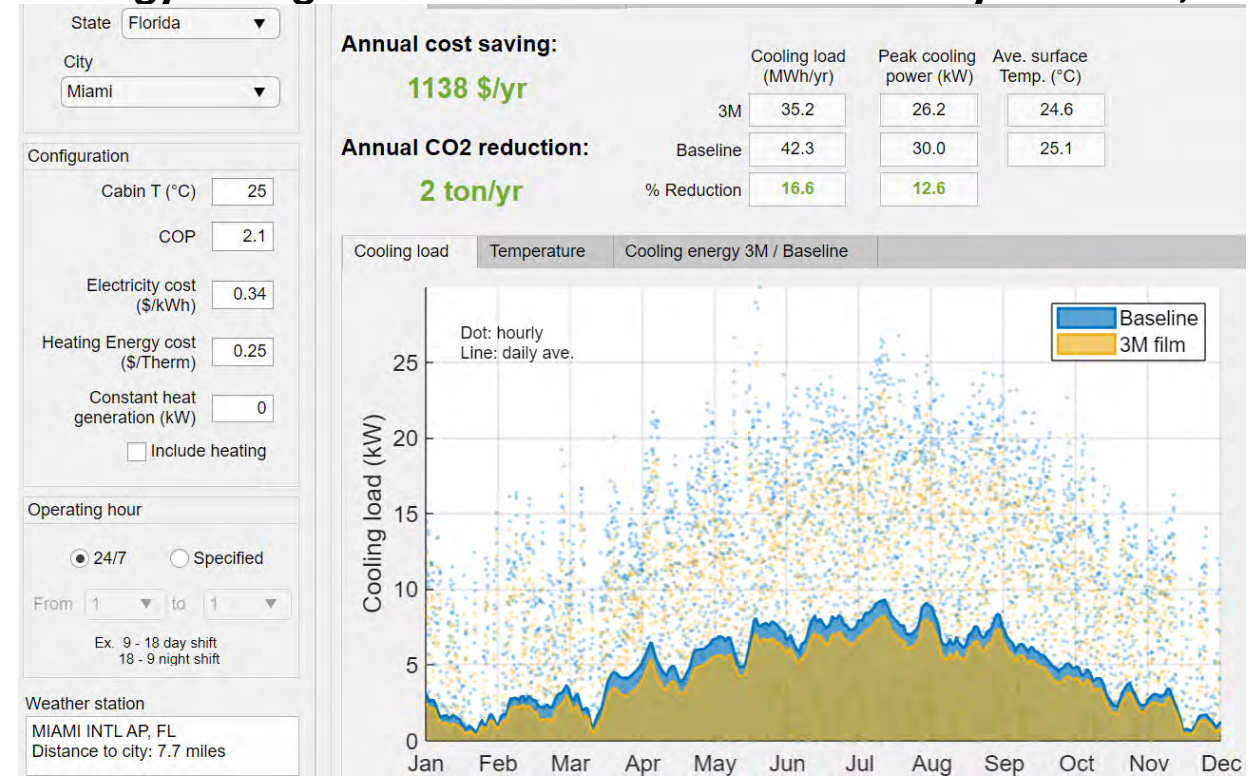


Energy Savings Model based on TMY3 (Typical Meteorological Year) climate data

Energy savings for buses with PRCF on roof only in Phoenix, AZ



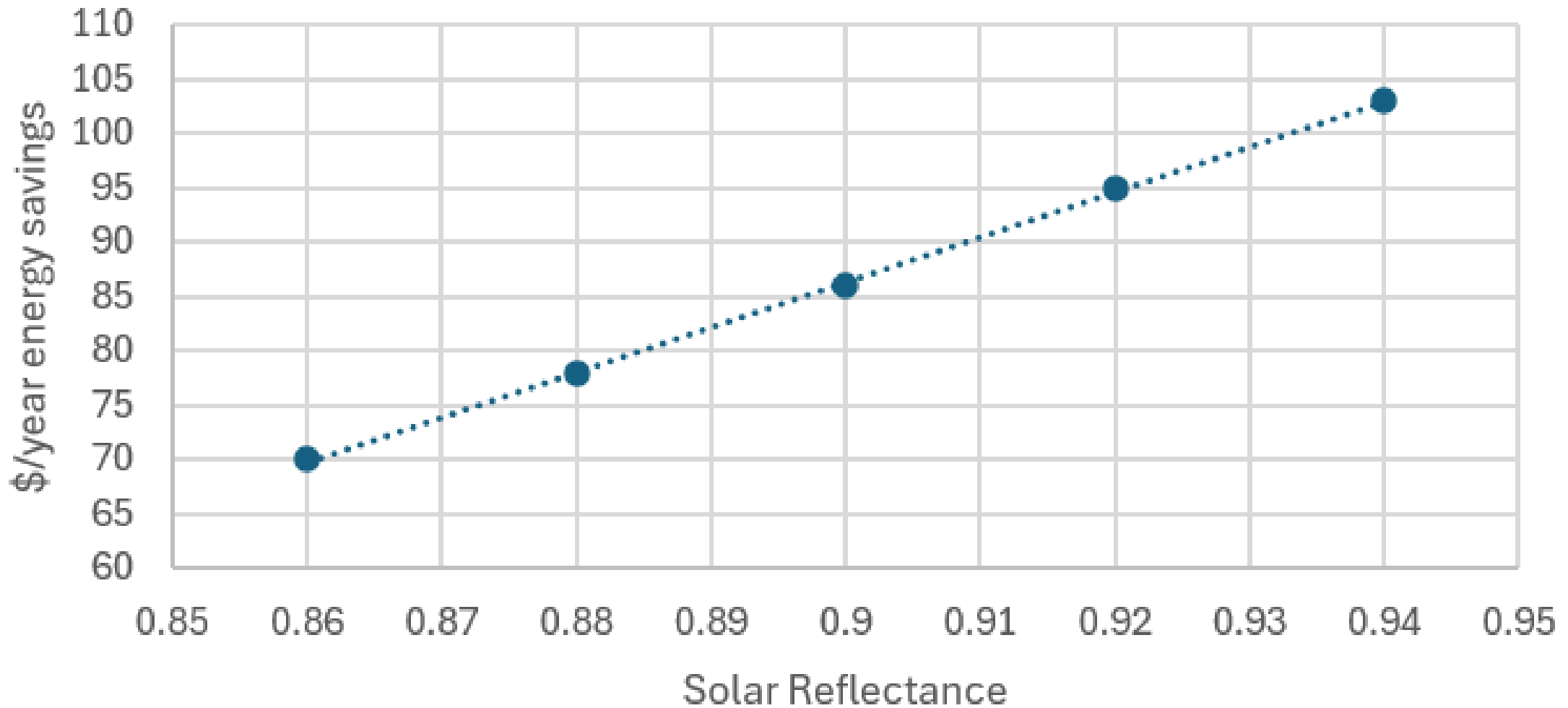
Energy savings for buses with PRCF on roof only in Miami, FL



$$\text{Cooling Power} = Q_{sky}(\text{radiation to sky}) + QC(\text{convection to ambient air}) - Q_{sun}(\text{radiation absorbed from sun})$$

$$= \sum_{\text{hours}} \left[\left(\epsilon \sigma (T_{surf}^4 - T_{sky}^4) \right) + \left(1.16 * (10.45 - wind + 10\sqrt{wind}) * (T_{surf} - T_{air}) \right) - Irradiance * \cos \theta_i (1 - R) \right]$$

ROI for a 10m2 Car Roof compared to white painted car roof assuming TE=0.90

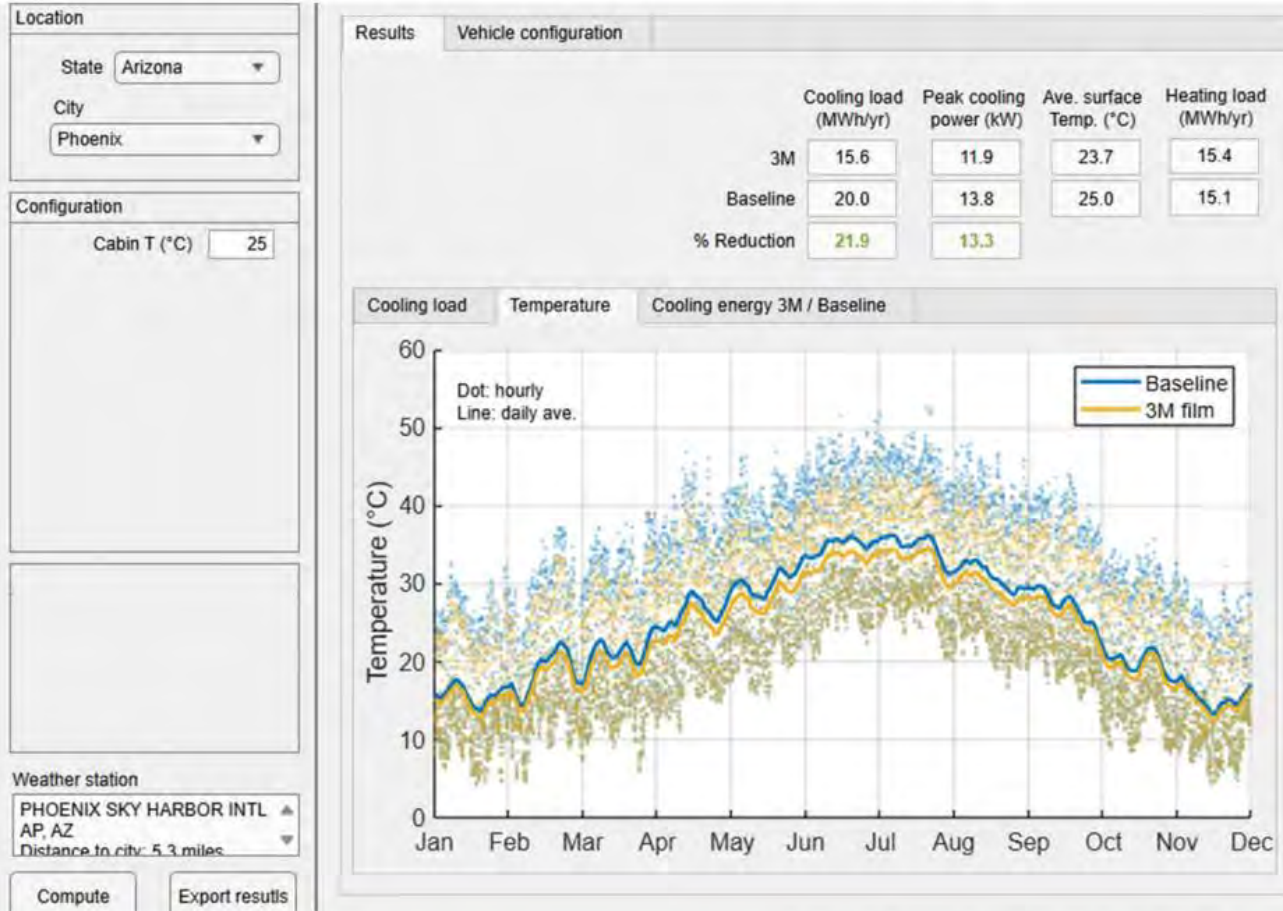


✓ High Solar Reflectance increases \$/savings, but **only** improves **ROI** if its cost increase is low

Electric commercial vehicle | modeling



Roof application in Phoenix, Arizona

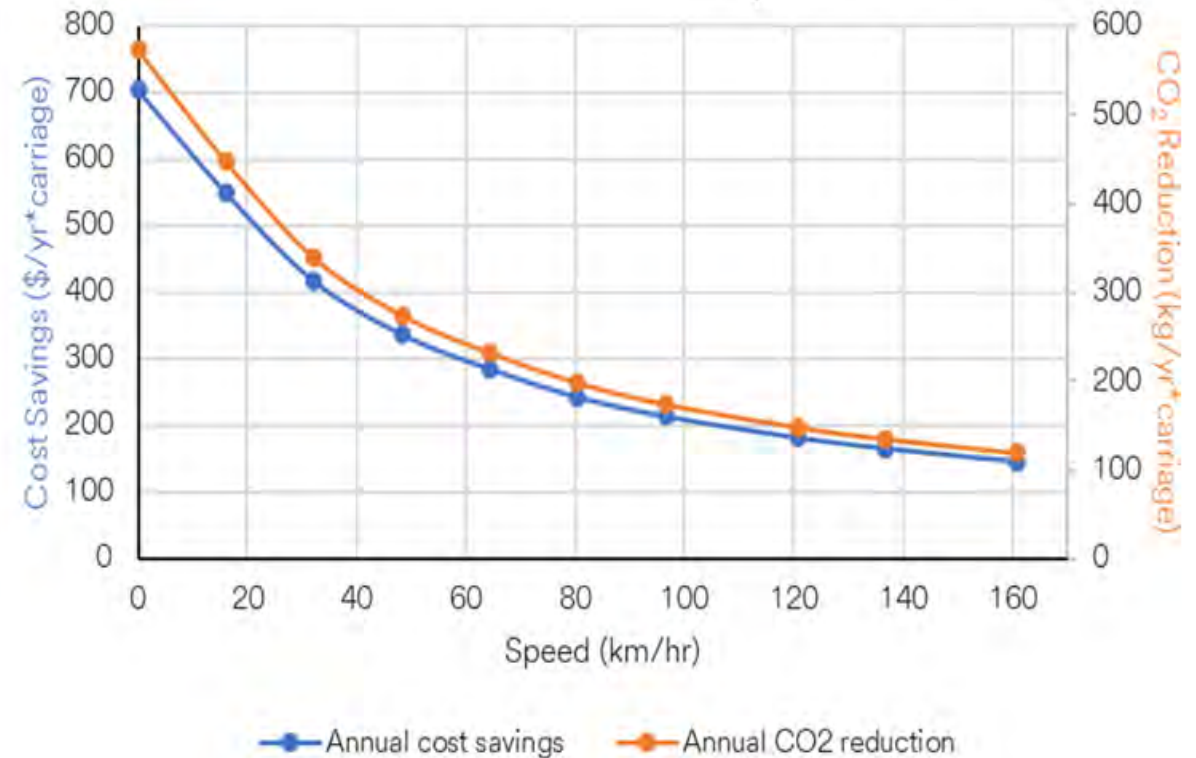
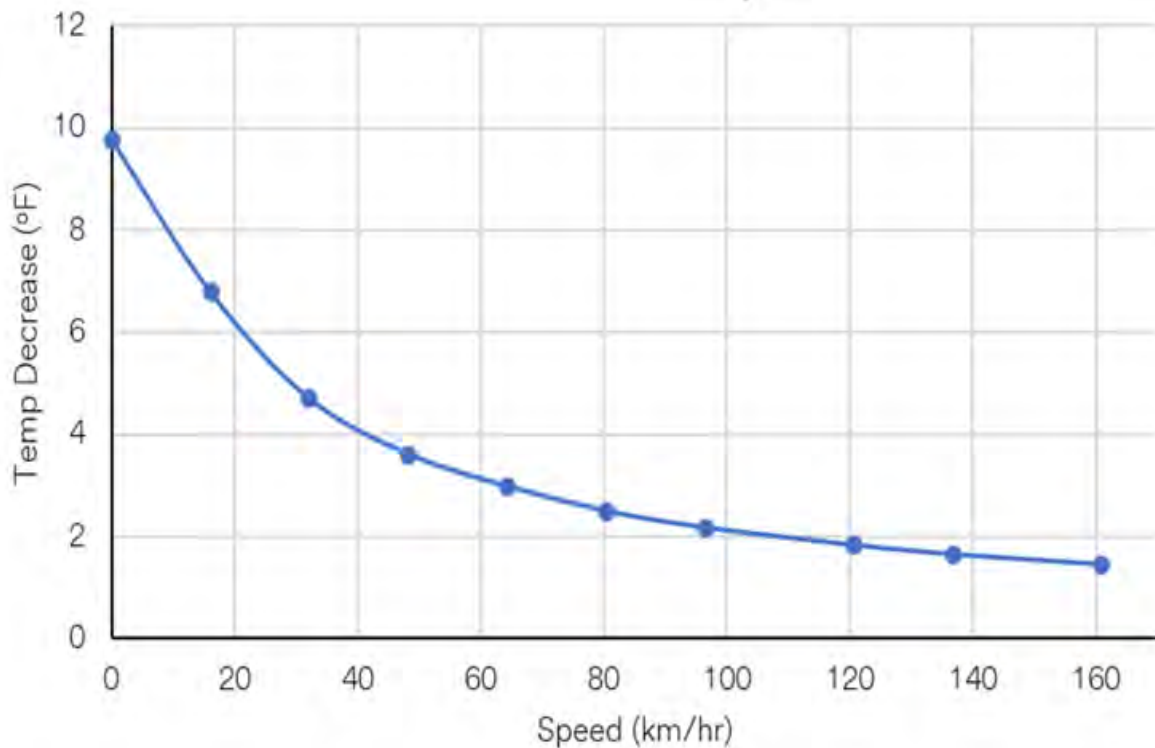


Property	Vehicle Paint (Baseline)	3M™ PRCF
Solar Reflectance	Initial: 8	85
Emissivity (typical)	Not measured	93
Est. Cooling in Vehicle Cargo † (Δ°F)	0 mph (avg / peak)	— / 9.3 / 15.1 °F
	25 mph (avg / peak)	— / 4.1 / 6.8 °F

† - Modeled based on 10 years of weather data

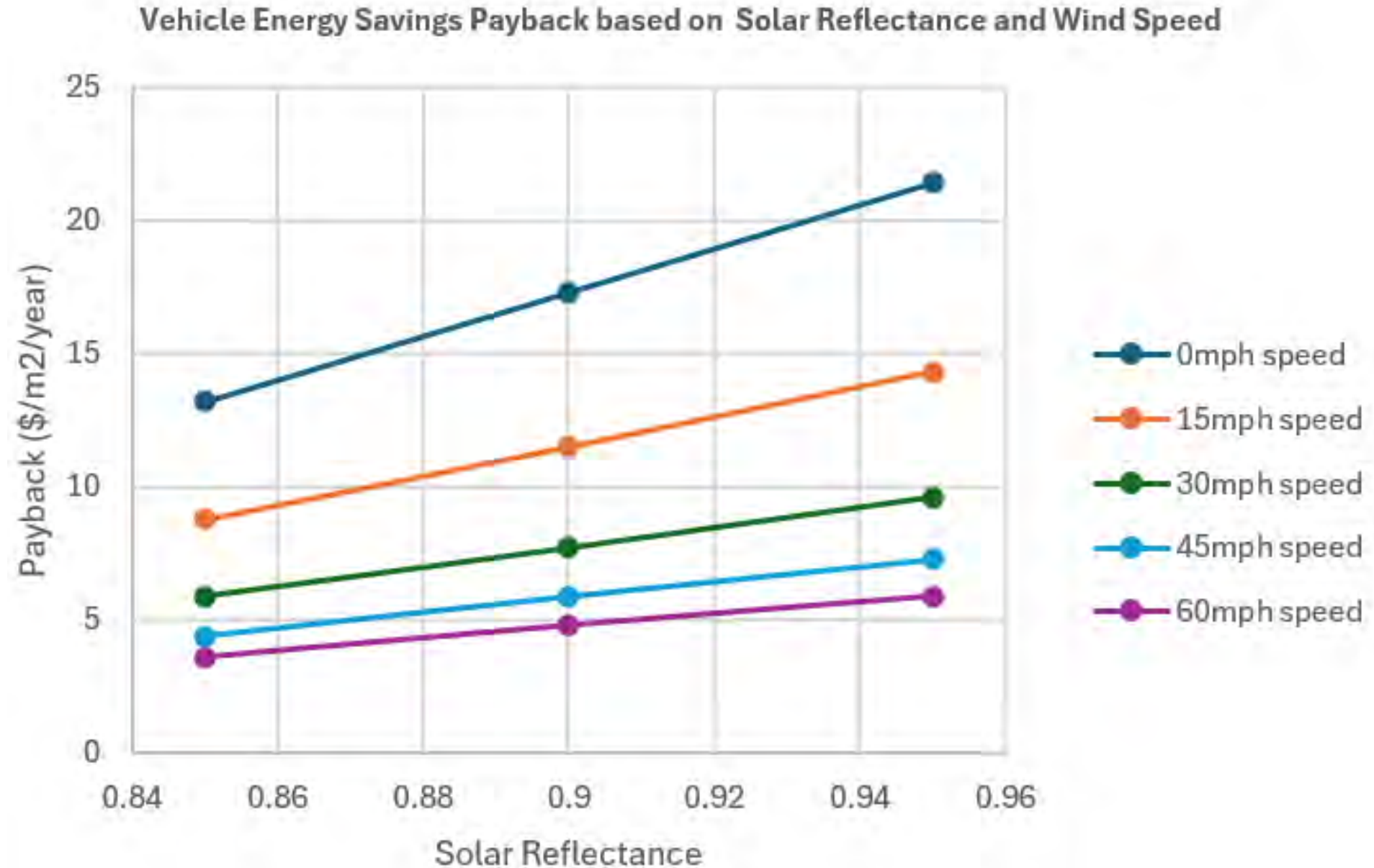
3M model predicted an average temperature reduction of 9.3°F with 3M Cooling Film and a peak cooling of 15 °F in Phoenix, Arizona, USA from May to September

Impact of vehicle speed (or average wind speed) is significant
→ Convective cooling/heating dominates over radiative cooling at higher vehicle/wind speeds



Key questions are “are customers willing to pay more for an improvement in comfort (temperature reduction) than they are for energy (cost) savings?” and “are customers willing to pay more for mitigating the Urban Heat effect?”

Benefit of high Solar Reflectance decreases at higher vehicle/wind speeds



Passive Cooling Films having color and high Solar Reflectivity

Comparison of 3 versions of colored passive cooling film on low slope roof viewed from street
*actual appearance is more specular (glossy) than shown in images below

Dark blue Passive Cooling Film

Orange Passive Cooling Film

Light blue Passive Cooling Film



Solar Reflectance=0.90
Thermal Emittance=0.88

Solar Reflectance=0.91
Thermal Emittance=0.88

Solar Reflectance=0.92
Thermal Emittance=0.91

Telecommunication Cabinet PRCF Field Testing

2025 data collected on Telecom cabinets West of San Antonio, TX

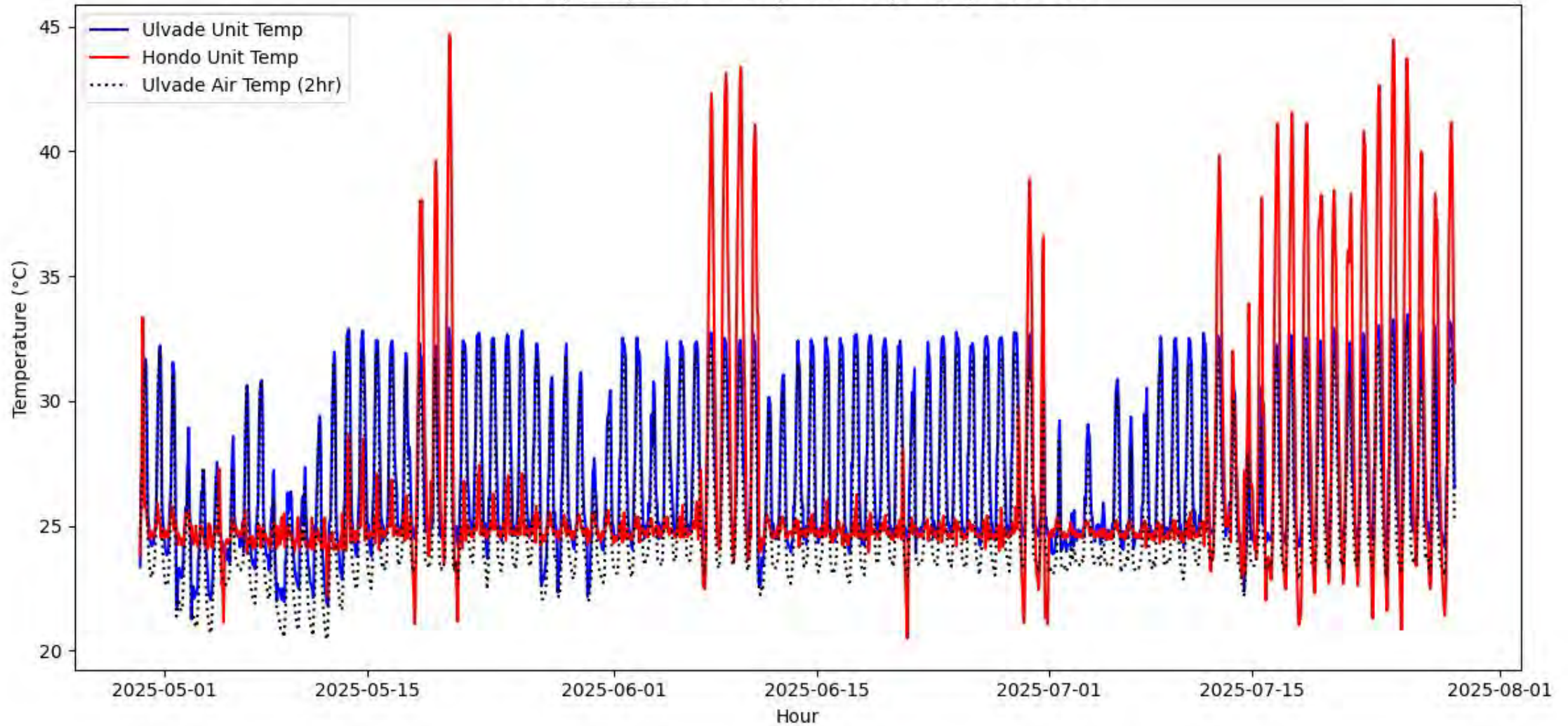


What is a telecommunication cabinet?

- **Outdoor electrical cabinets that house fiber optics connections and computer servers**
- **Often air conditioned**
- **Can fail at high temperatures if air conditioner is undersized or stops working**



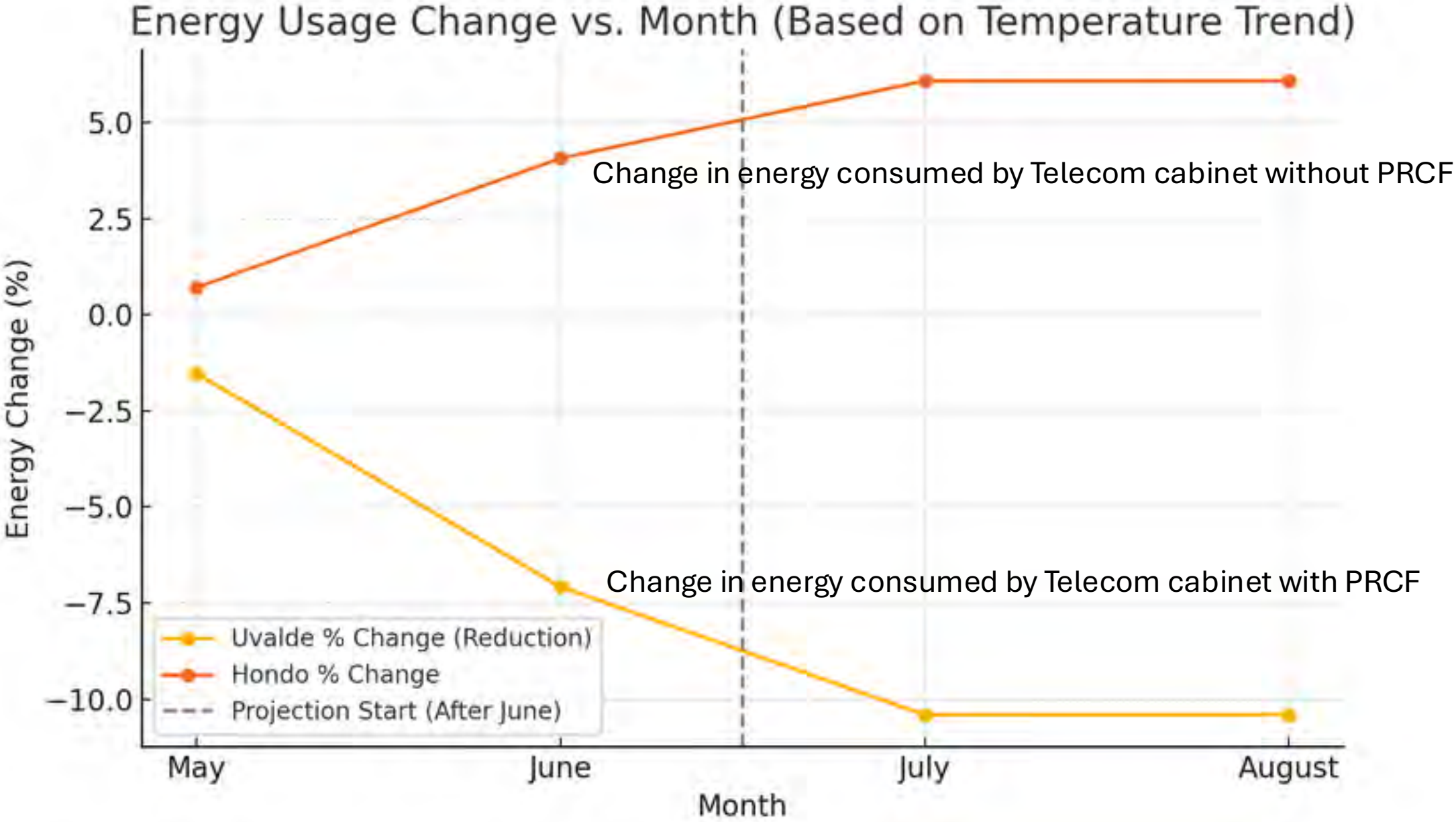
Hourly Temperature Comparison (Up to July 28, 2025)



*** Internal temperature of telecom cabinet without PRCF frequently exceeds 100F which is a problem for telecom reliability**

*** Internal temperature of telecom cabinet with PRCF does not exceed 95F.**

Energy consumed by air conditioning units on two Telecom cabinets near San Antonio, TX



Student-led Solar Vehicle Project team wins the 2022 American Solar Challenge

3M Anti-Reflective and Drag Reduction Film applied to solar modules on roof of University of Minnesota Solar Vehicle.



The Cannonball Sun

NY TO LA

3100 MILES

SUNPOWER ONLY



Gen4 PRCF on Driver Canopy





ARE THERE ANY QUESTIONS?

Tim Hebrink, Senior Scientist, email: thebrink@mmm.com, cell# 651-755-2739