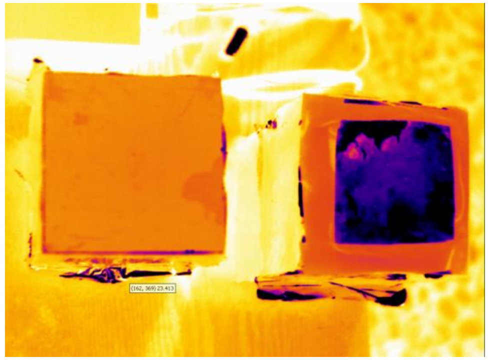
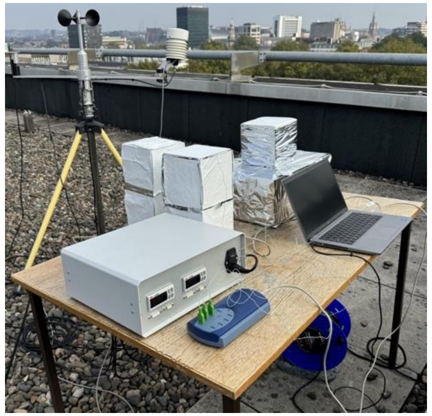
Photonic Innovations Lab UCL

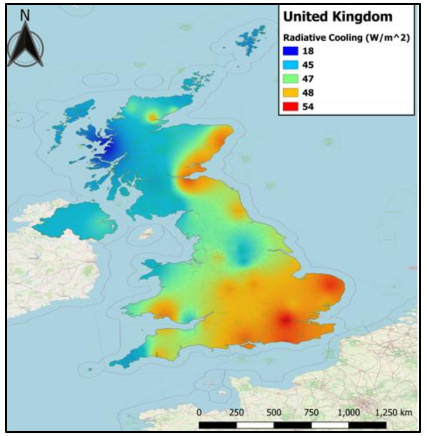
Oxford Energy Network, March 2025

UCL

Harvesting Energy from the Cold Universe: The Missing Piece in the Renewables Puzzle?







Prof Ioannis Papakonstantinou

Photonic Innovations Lab, Department of Electronic and Electrical Engineering, UCL

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HORIZON 2020

Integrated Photonic & Electronic Systems
UCL & Cambridge Centre for

Lloyd's Register Foundation

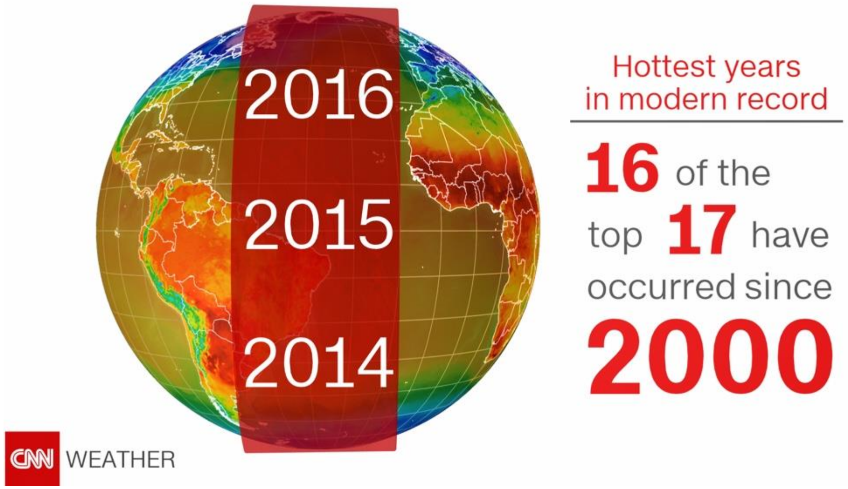
ROYAL ACADEMY OF ENGINEERING

Defence and Security Accelerator

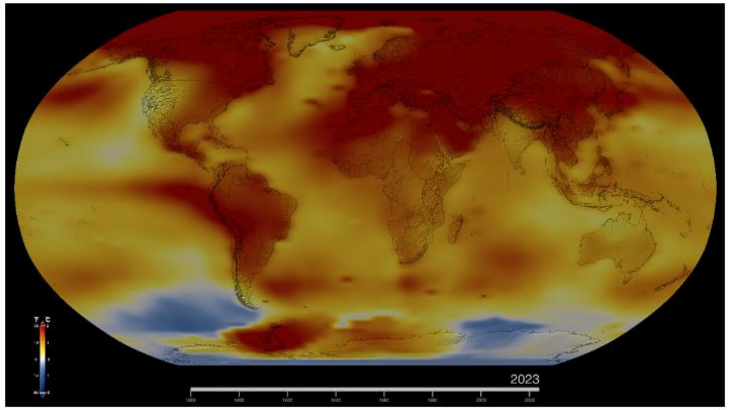
Objectives of the talk

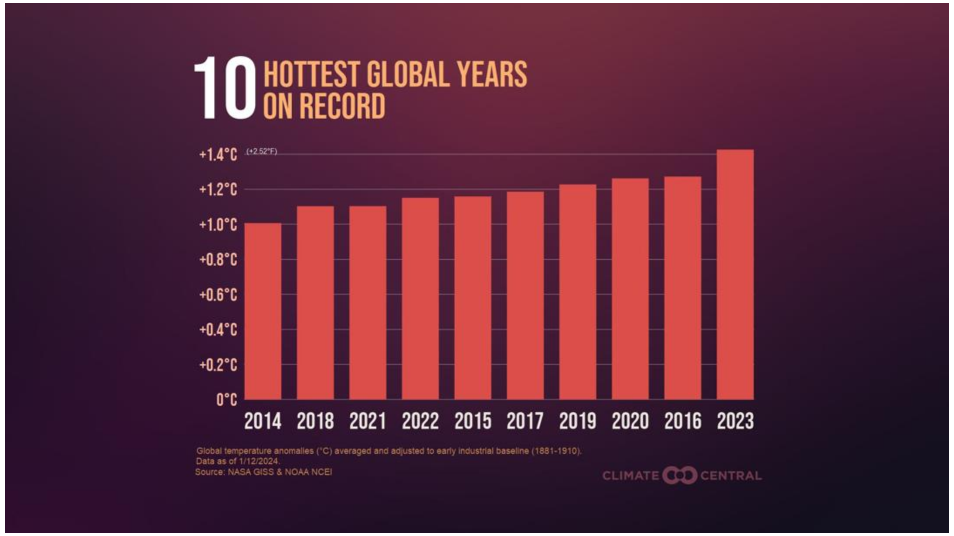
- **Obj 1**: Make the case that cooling is a real obstacle to net-zero transition
- **Obj 2**: Establish radiative cooling as a viable, electricity-free solution to traditional cooling methods
- **Obj 3**: Introduce the “cold” universe as an additional renewable resource in the fight against climate change
- **Obj 4**: Raise awareness in the field

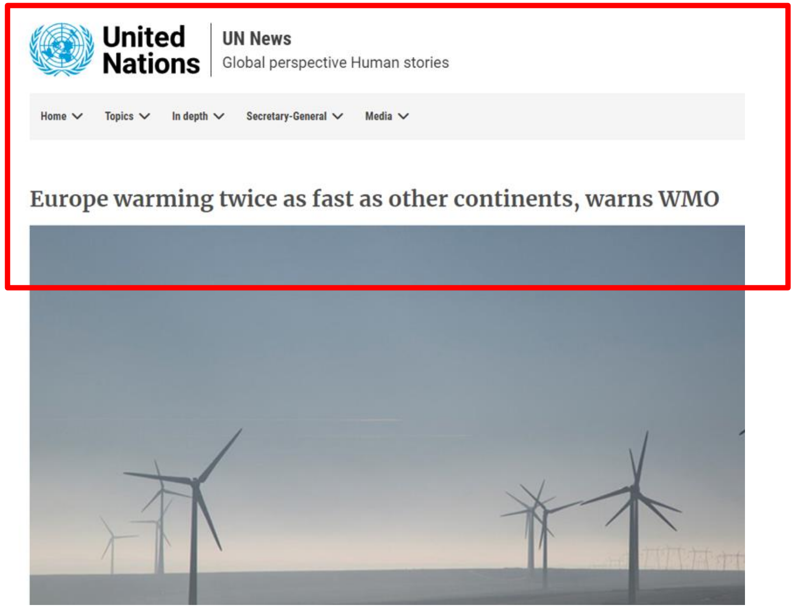
Motivation for sustainable cooling



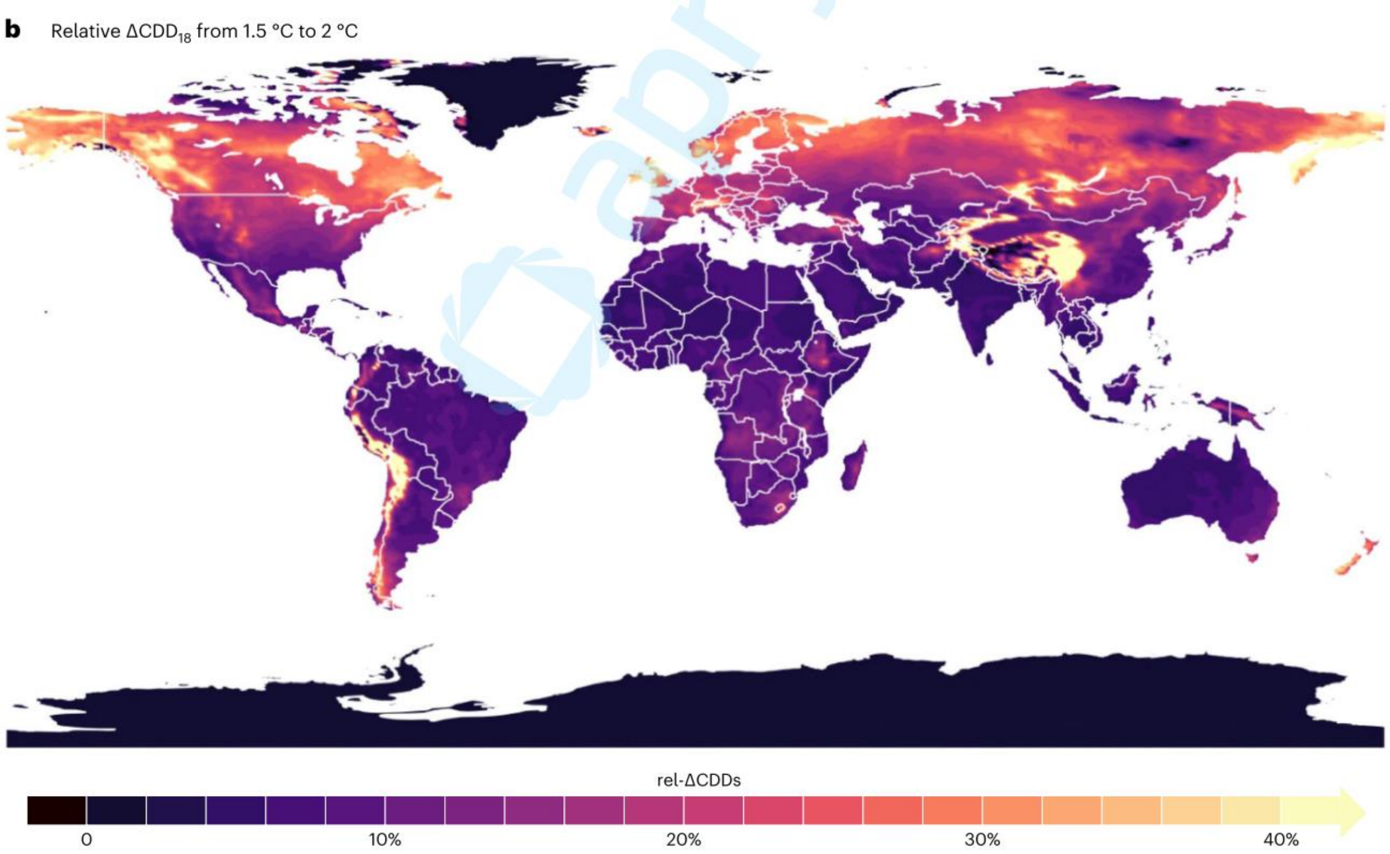
NASA Analysis Confirms 2023 as Warmest Year on Record







Need for Cooling and the UK

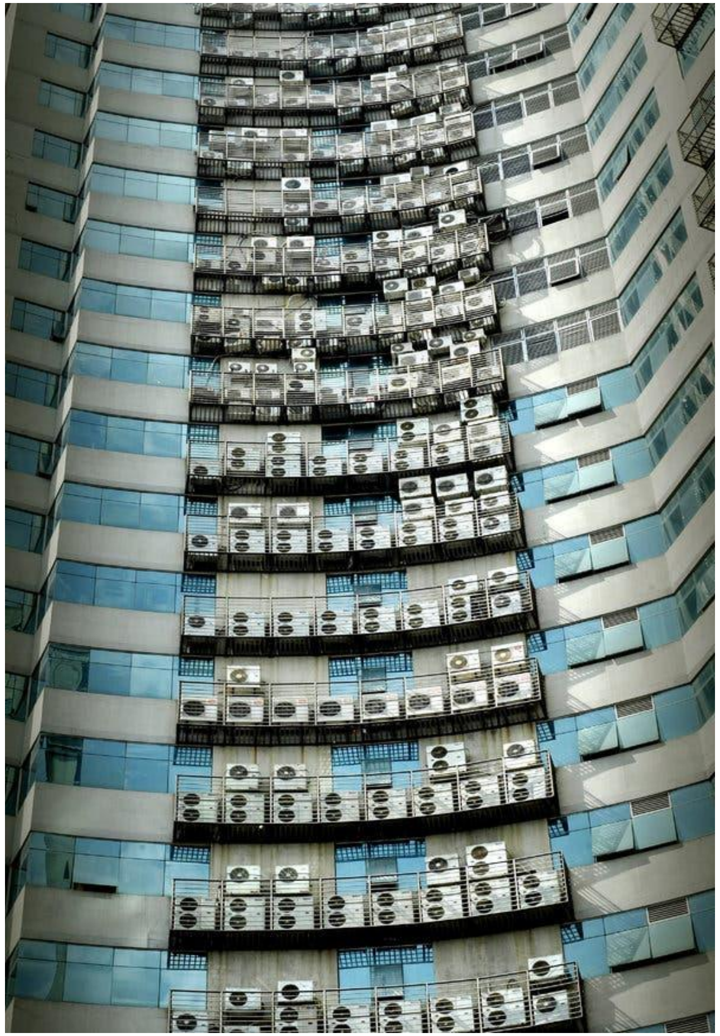


Top ten countries by relative change	rel-ΔCDD_{18}
Switzerland	30%
United Kingdom	30%
Norway	28%
Finland	28%
Sweden	28%
Austria	24%
Canada	24%
Denmark	24%
New Zealand	24%
Belgium	21%

Miranda, N. D., Lizana, J., Sparrow, S. N., Zachau-Walker, M., Watson, P. A. G., Wallom, D. C. H., Khosla, R., & McCulloch, M.. Change in cooling degree days with global mean temperature rise increasing from 1.5 °C to 2.0 °C. *Nature Sustainability*, *6*(11), 1326–1330, 2023.

Electricity and CO_2

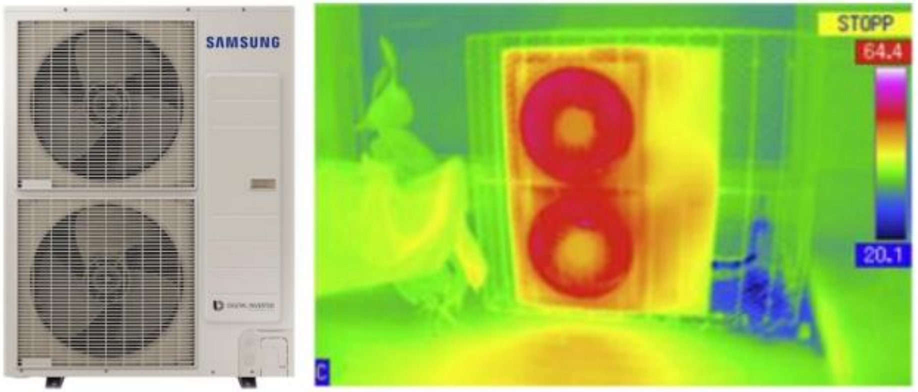
- Electricity consumption due to space cooling surpassed 2,400 TWh in 2022
- CO_2 equivalent emissions exceeded 1.3 GT
- Demand for cooling is growing in double digits Worldwide
- By 2050, >300m AC units will be sold per year

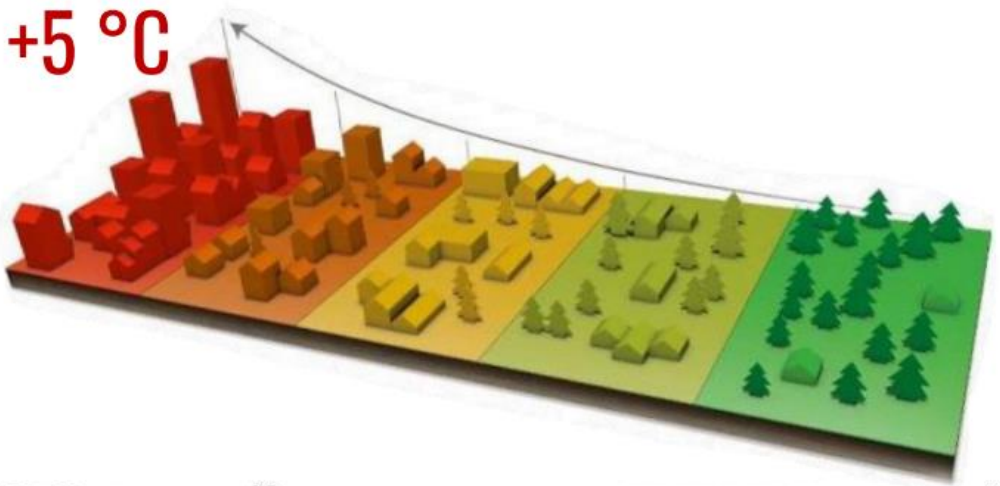


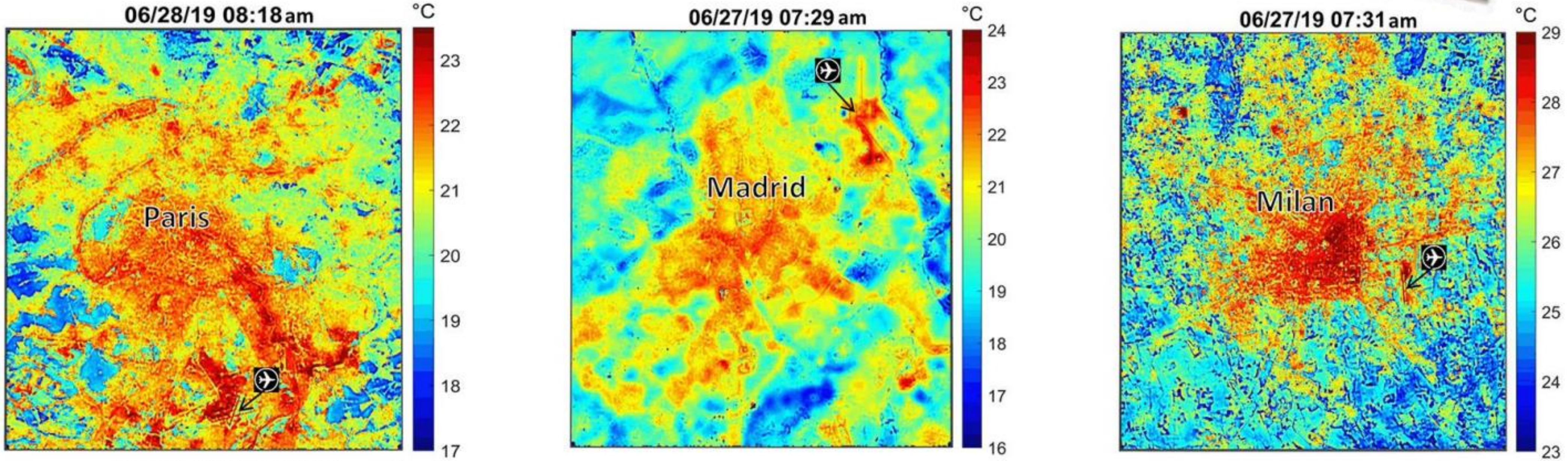
The Great Cooling Paradox

Net-zero amid explosive demand for new cooling capacity

The vicious cycle between cooling and urban heat island







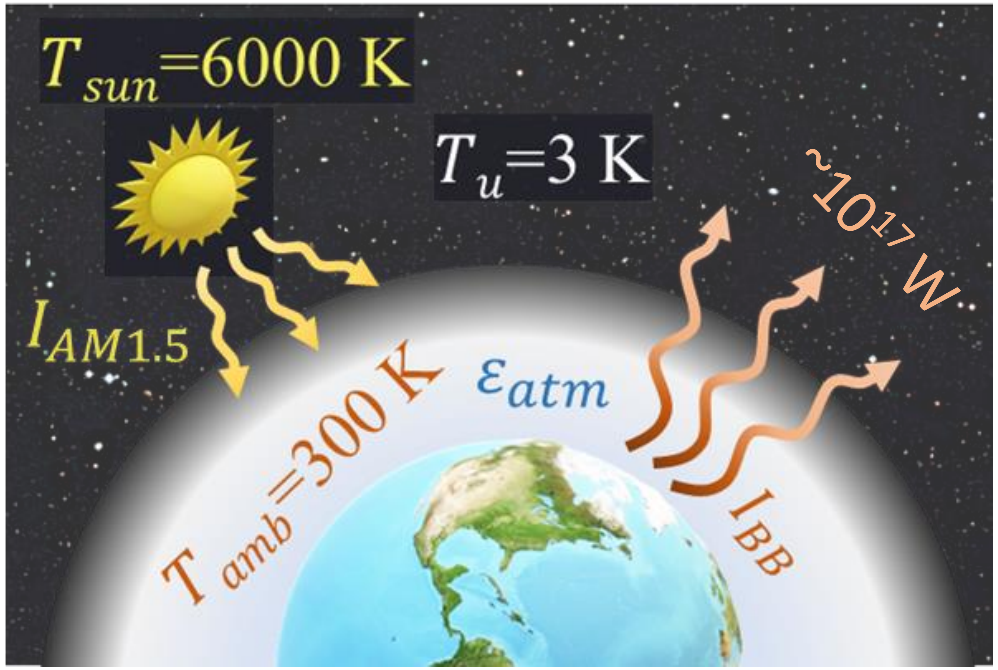
source: NASA ECOSTRESS project

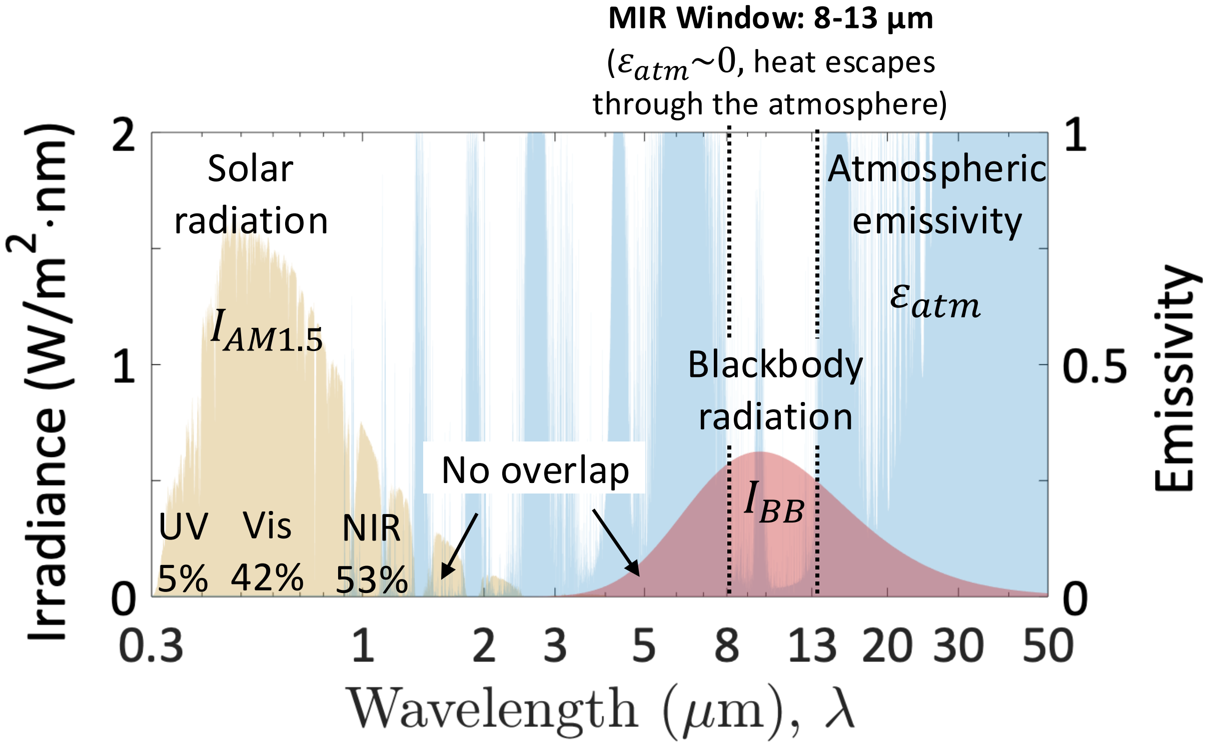
Lorenzo Pattelli, PaRaMetriC workshop presentation, 2024

Radiative Cooling as a green cooling solution

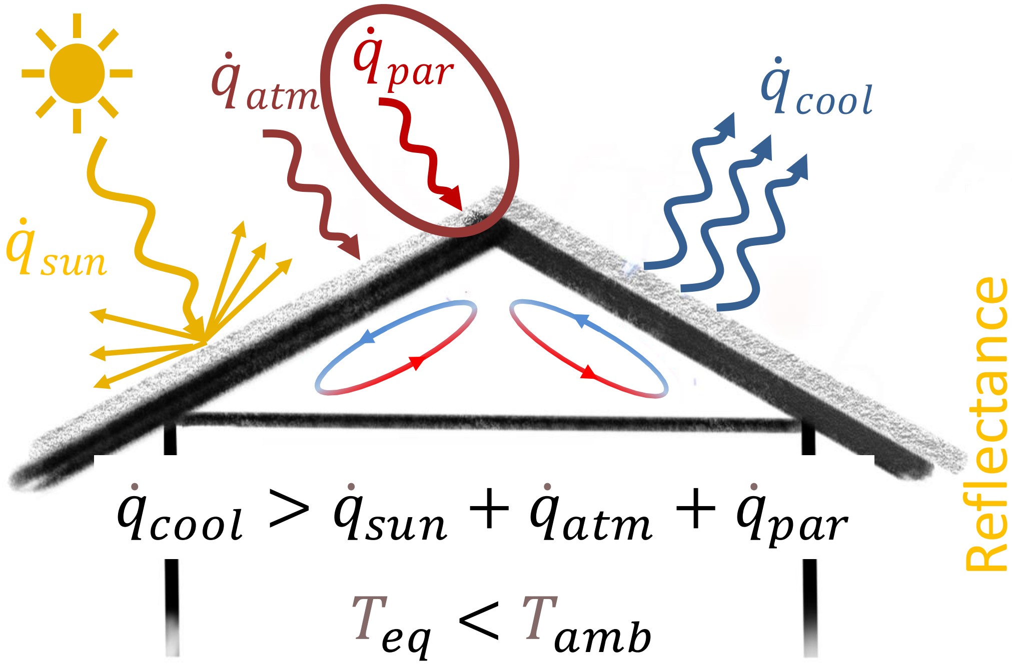
!! Temperature difference can exceed 45C in Sahara !!

Radiative Cooling Principles

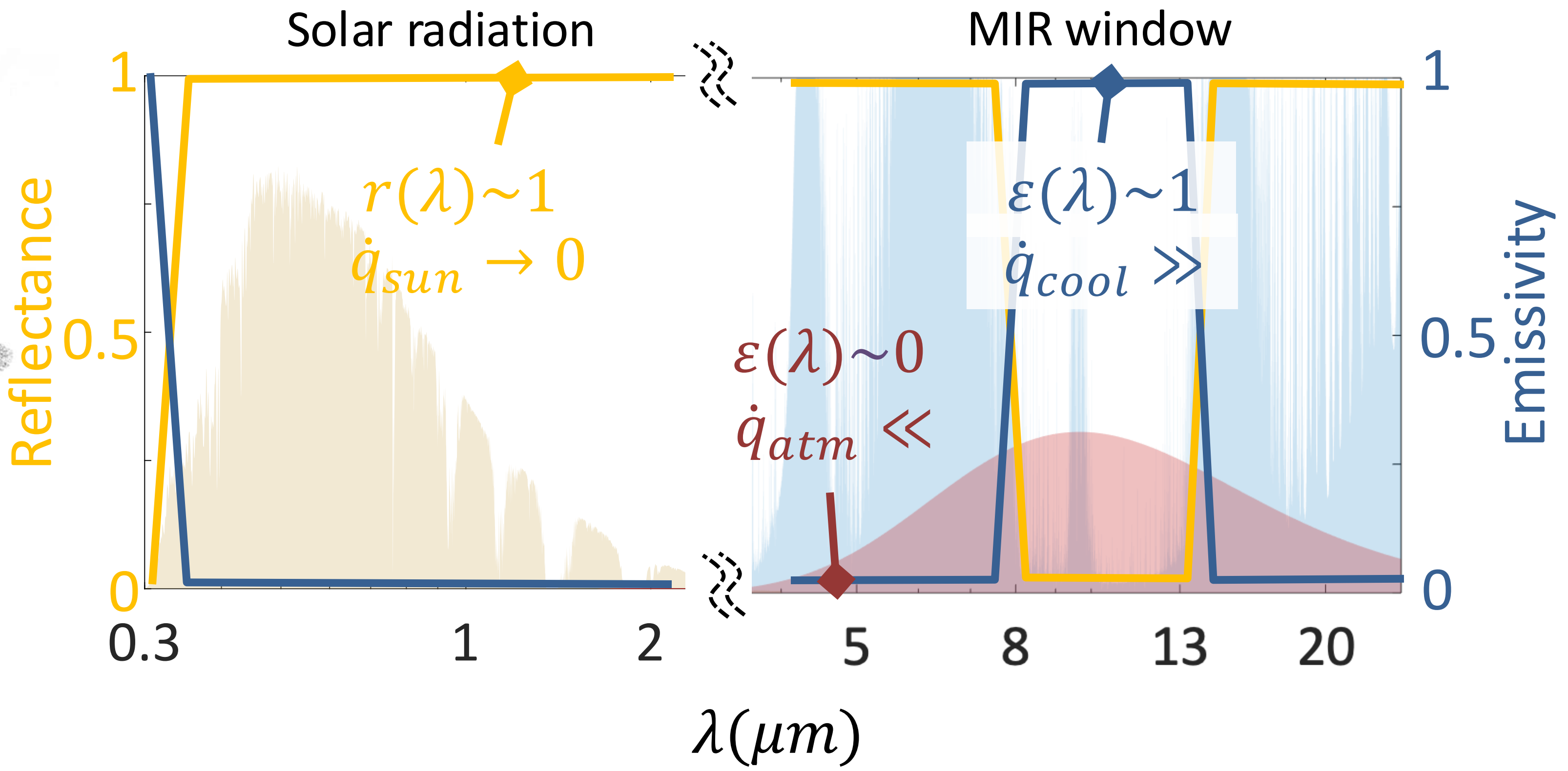




Radiative Cooling Principles



$$r(\lambda) + \varepsilon(\lambda) = 1$$

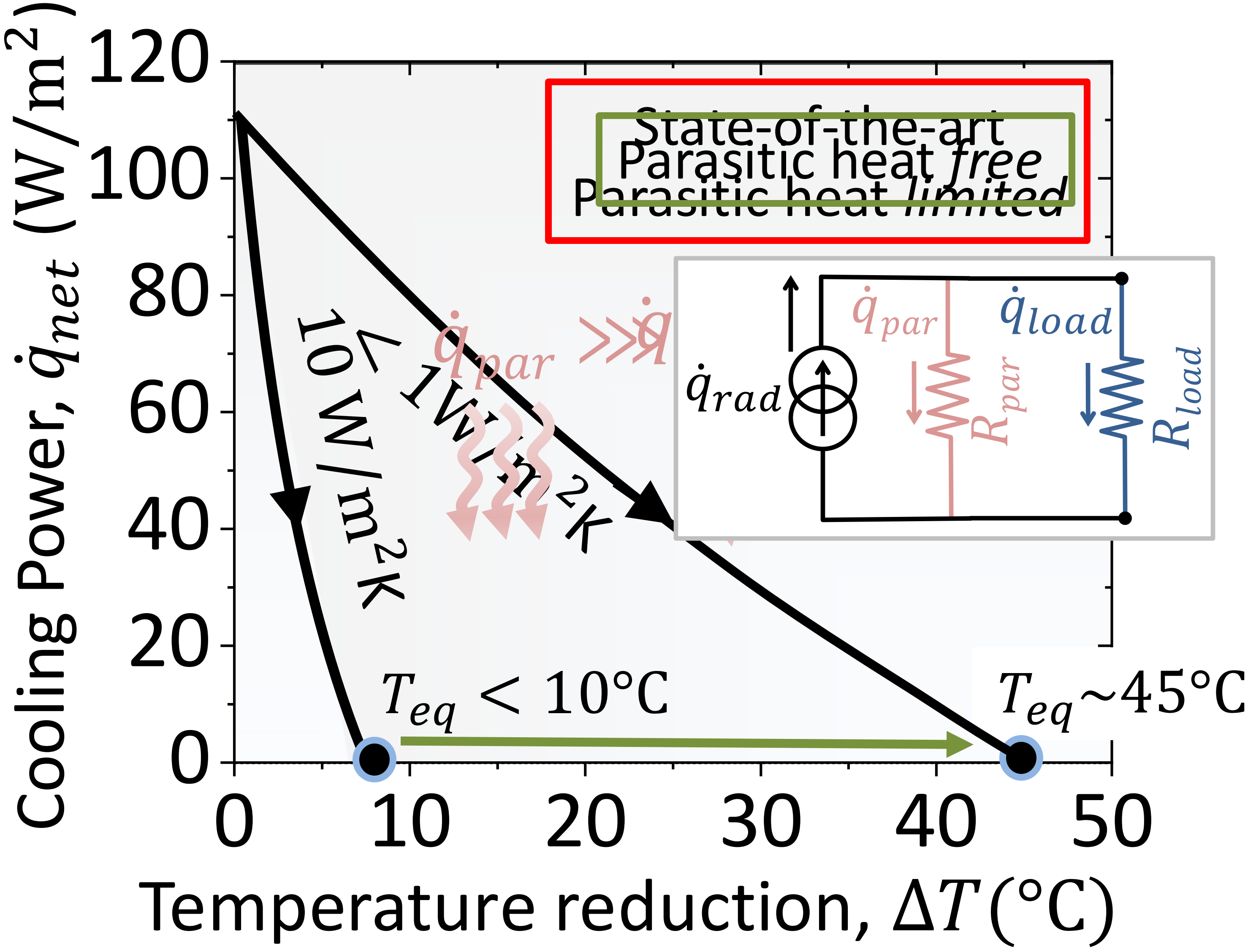


Thermodynamic limits

- State-of-art systems suffer from excessive heat losses (10 $\mathrm{W/m^2K}$)
- Field is stuck at <10 °C cooling
- When heat losses ~1 $\mathrm{W/m^2K}$, cooling may exceed 45 °C!

<u>Main Chalenge</u>

Reducing parasitic heat losses is very challenging but holds the key to passive refrigeration

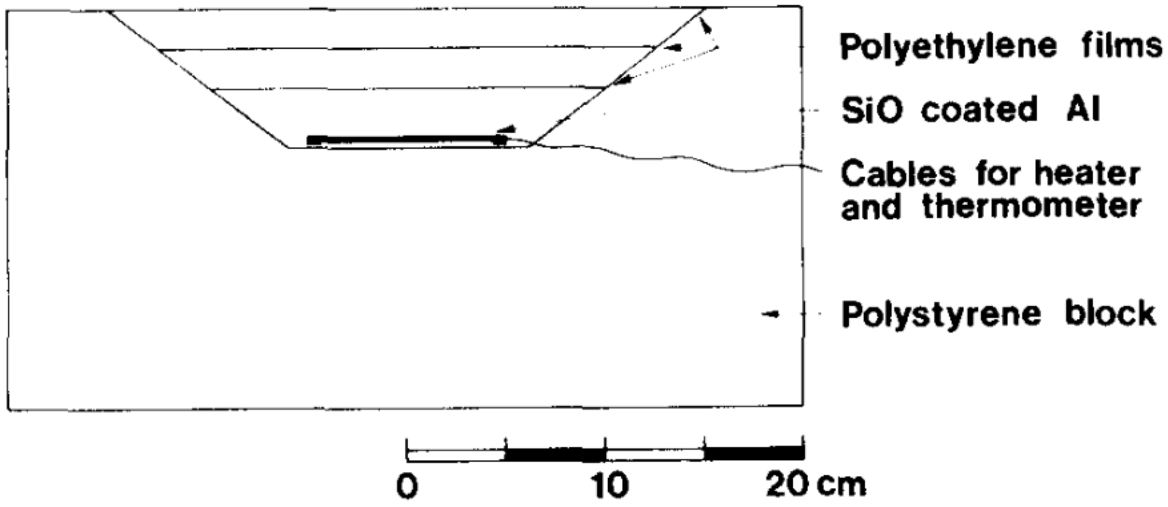


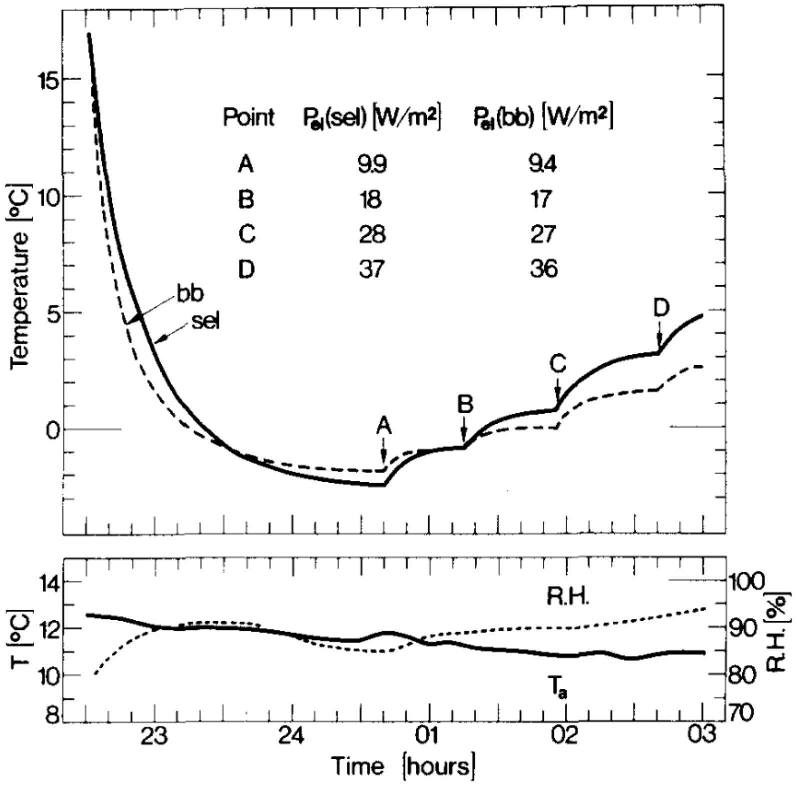
The early days. Nightime cooling

Radiative cooling to low temperatures: General considerations and application to selectively emitting SiO films

C. G. Granqvist and A. Hjortsberg
Chalmers University of Technology, Department of Physics, S-412 96 Gothenburg, Sweden

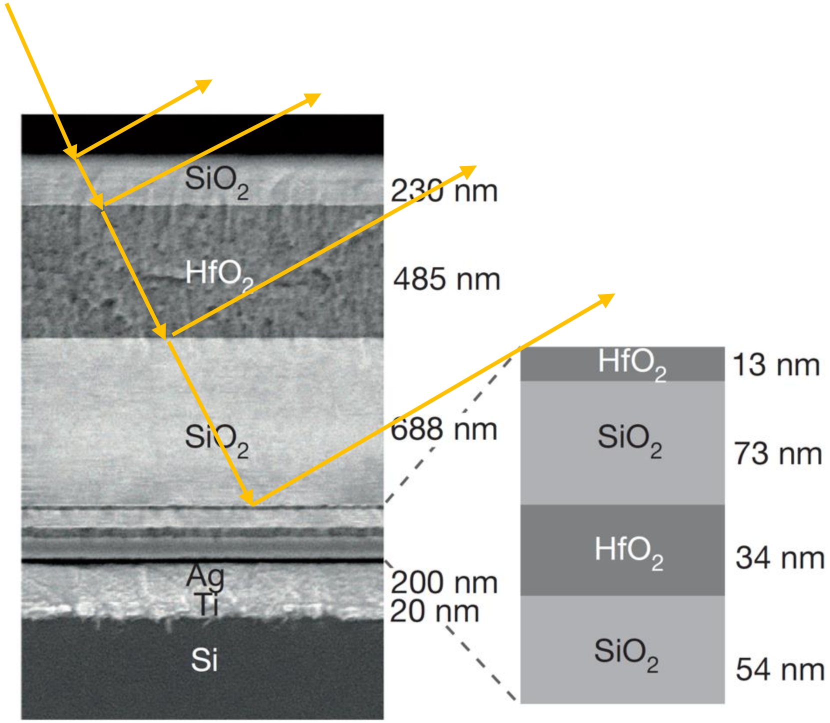
(Received 17 November 1980; accepted for publication 27 January 1981)

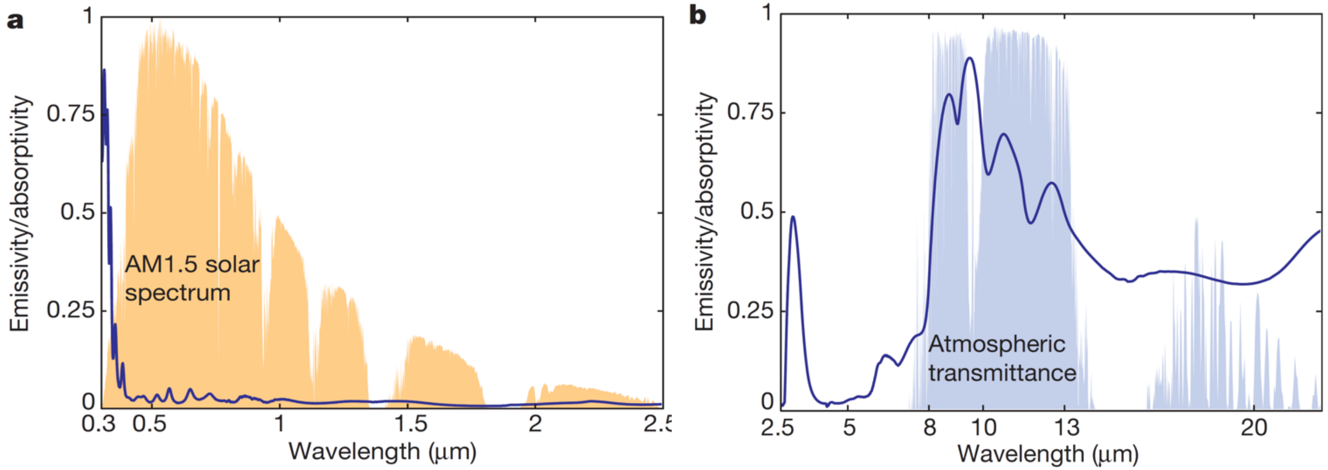


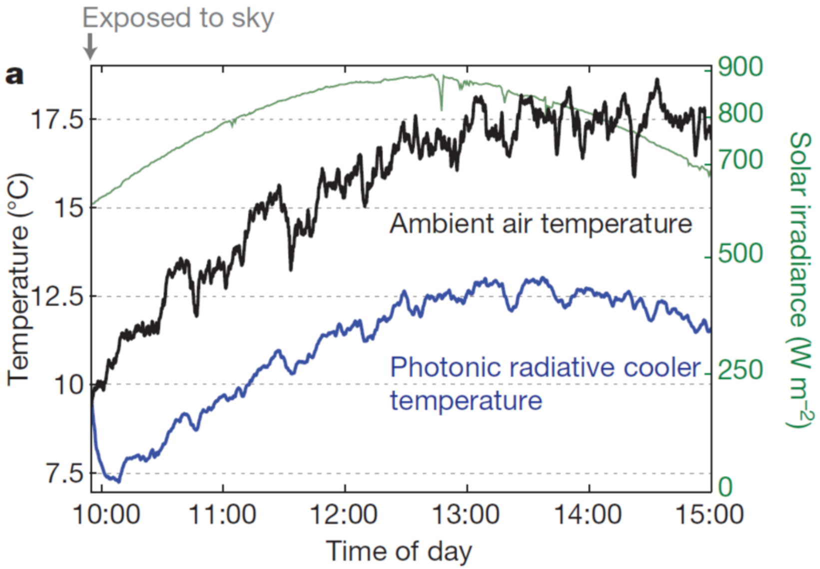


First Daytime Demonstration

PHOTONIC MULTILAYER STRUCTURE *Raman, A. et al (2014). Nature, 515(7528), 540–544*

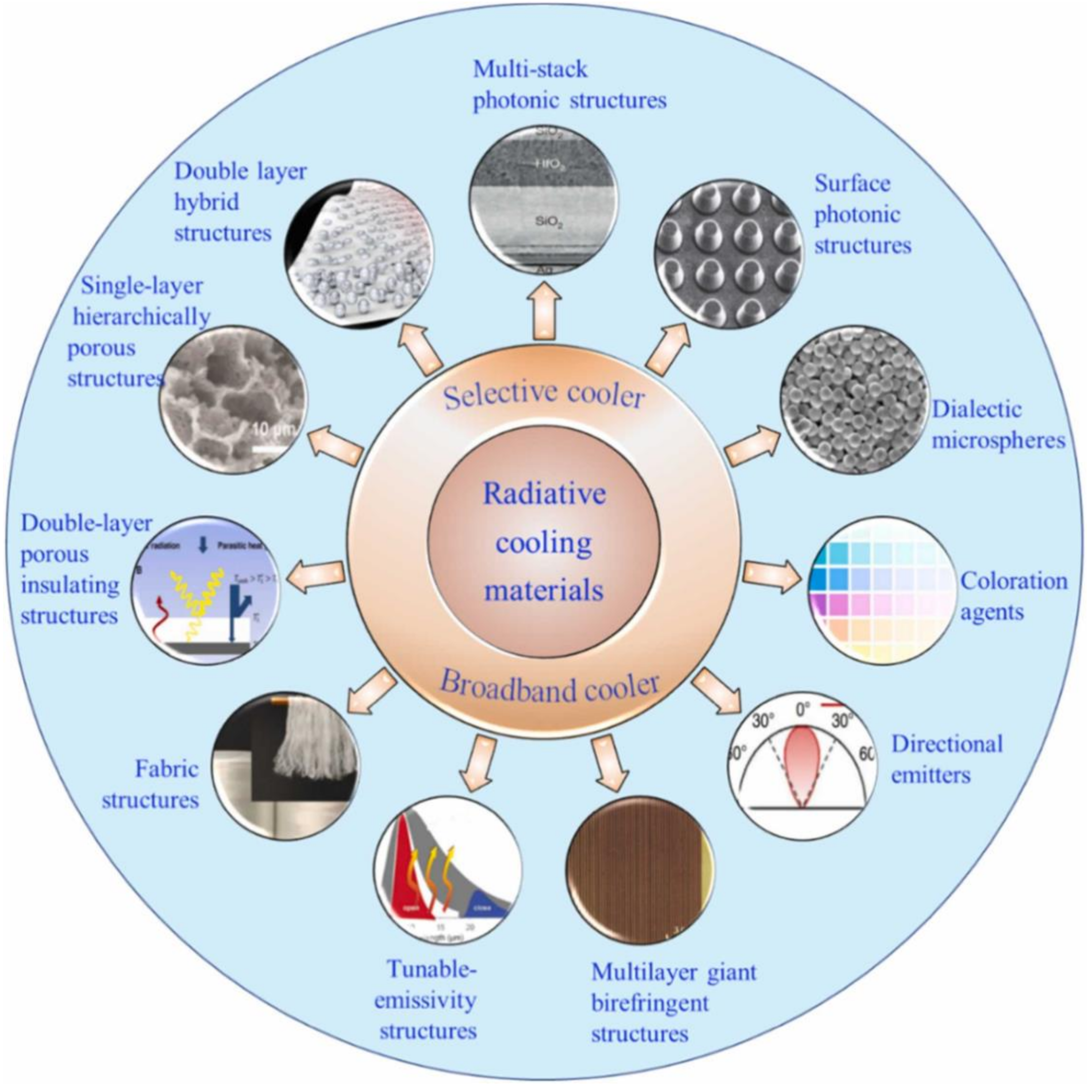






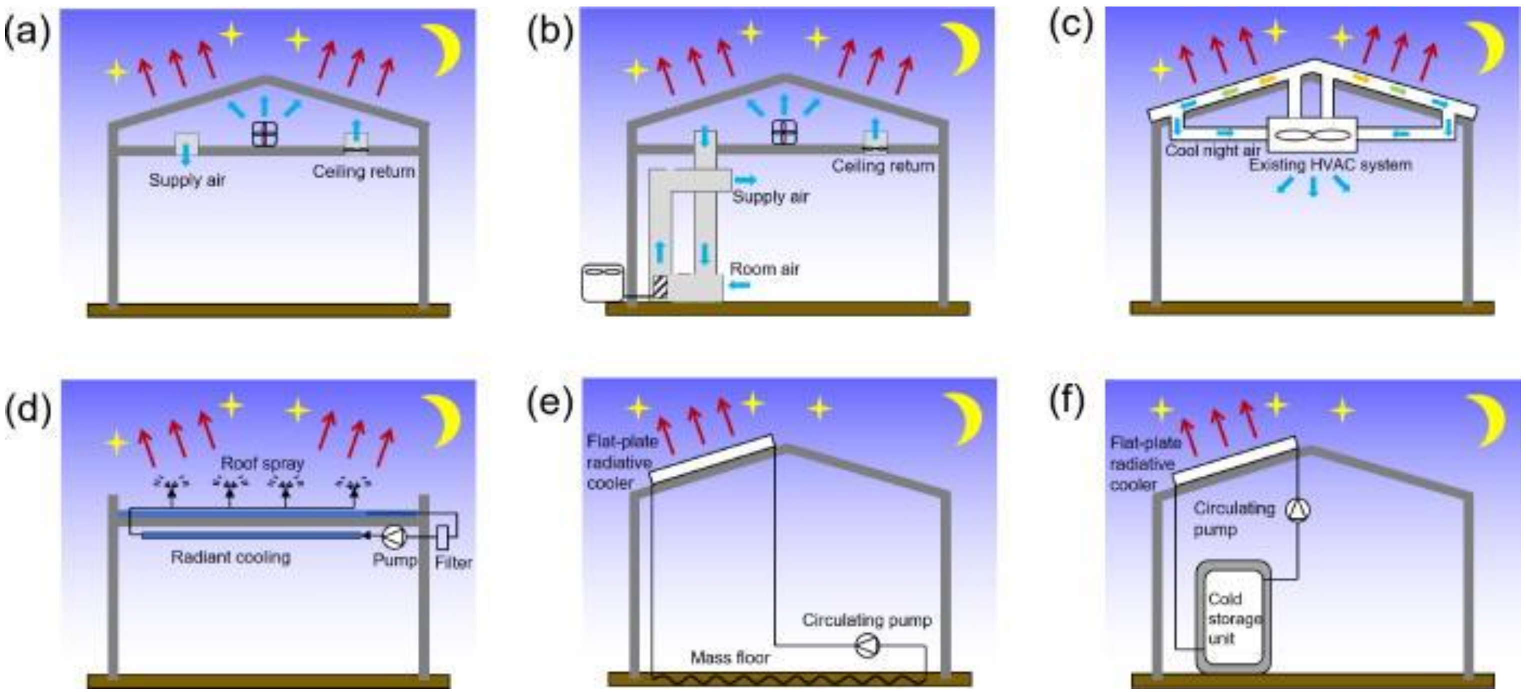
State-of-art Evolution

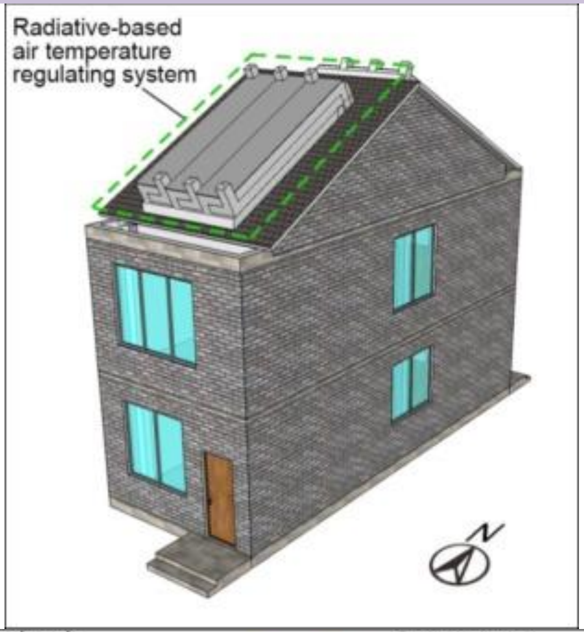
PASSIVE DAYTIME RADIATIVE COOLING: MOVING BEYOND MATERIALS TOWARDS REAL-WORLD APPLICATIONS, A Aili et al., *Next Energy*, 3, 2024

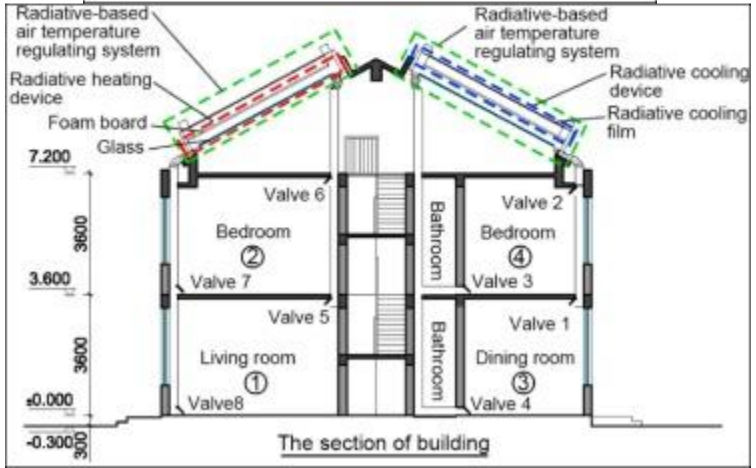


Application 1: Cooling of Buildings

Integration of Radiative-based air temperature regulating system into residential building for energy saving, Applied Energy, 301, 2021

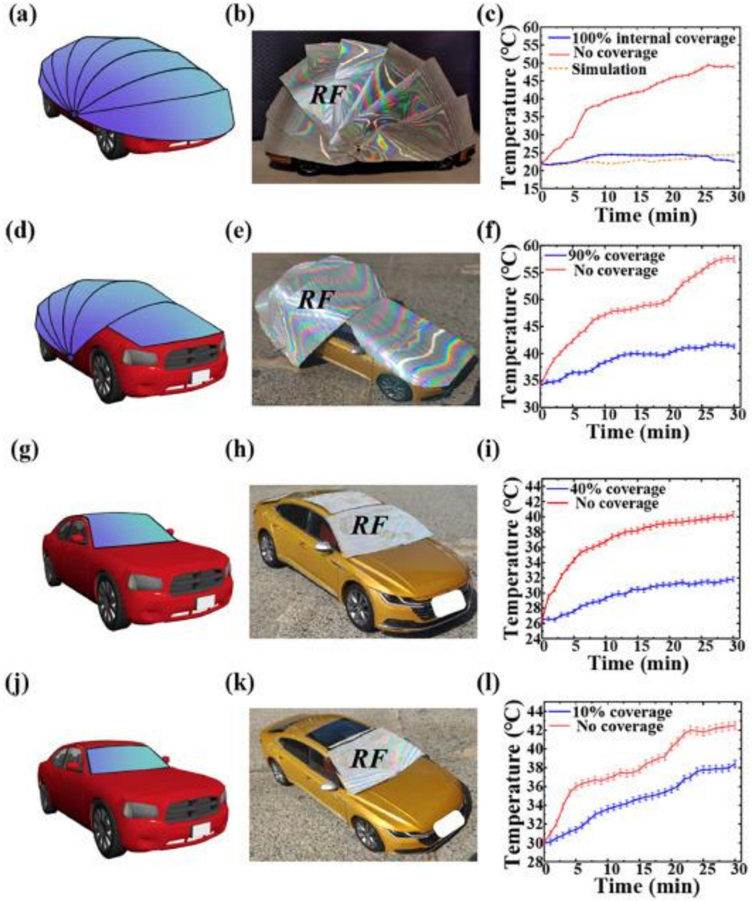


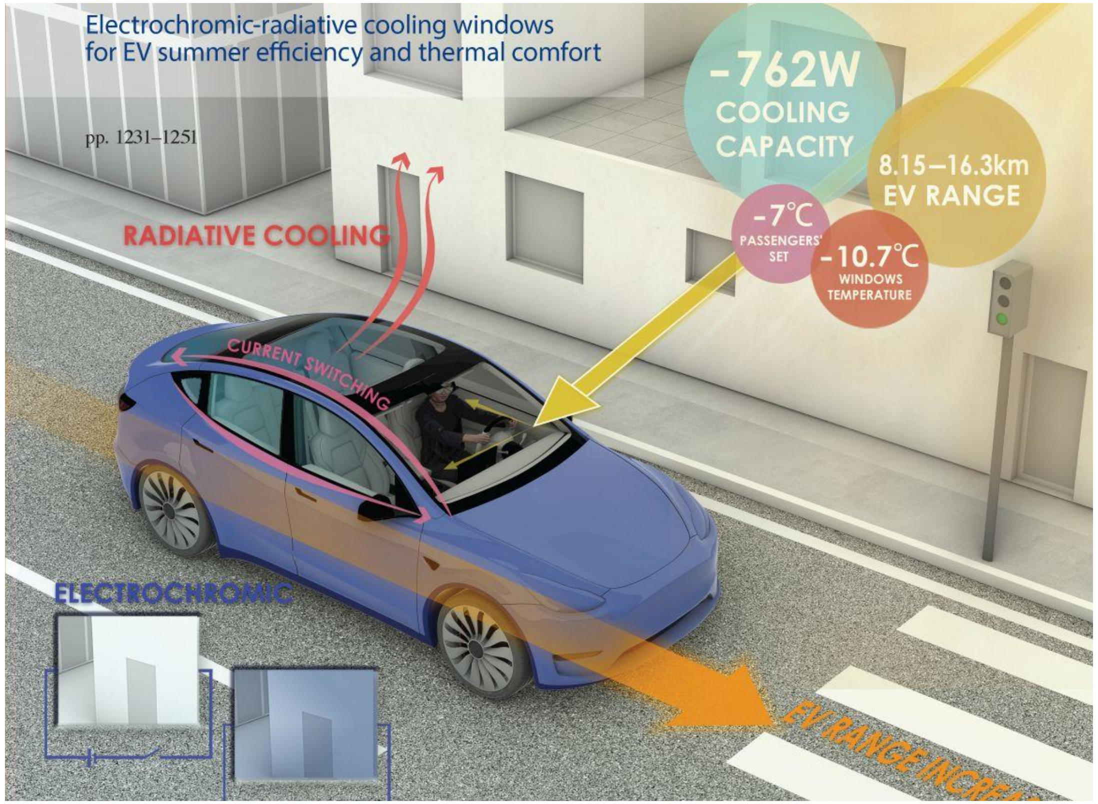




Application 2: Cooling of vehicles

Duan, Z., Wu, S., Sun, H. *et al.* Improvements in energy saving and thermal comfort for electric vehicles in summer through coupled electrochromic and radiative cooling smart windows. *Build. Simul.* **17**, 1231–1251 (2024)
Design of radiative cooling covers for automobiles with maximized cooling power, *International Journal of Heat and Mass Transfer*, 227, (2024)



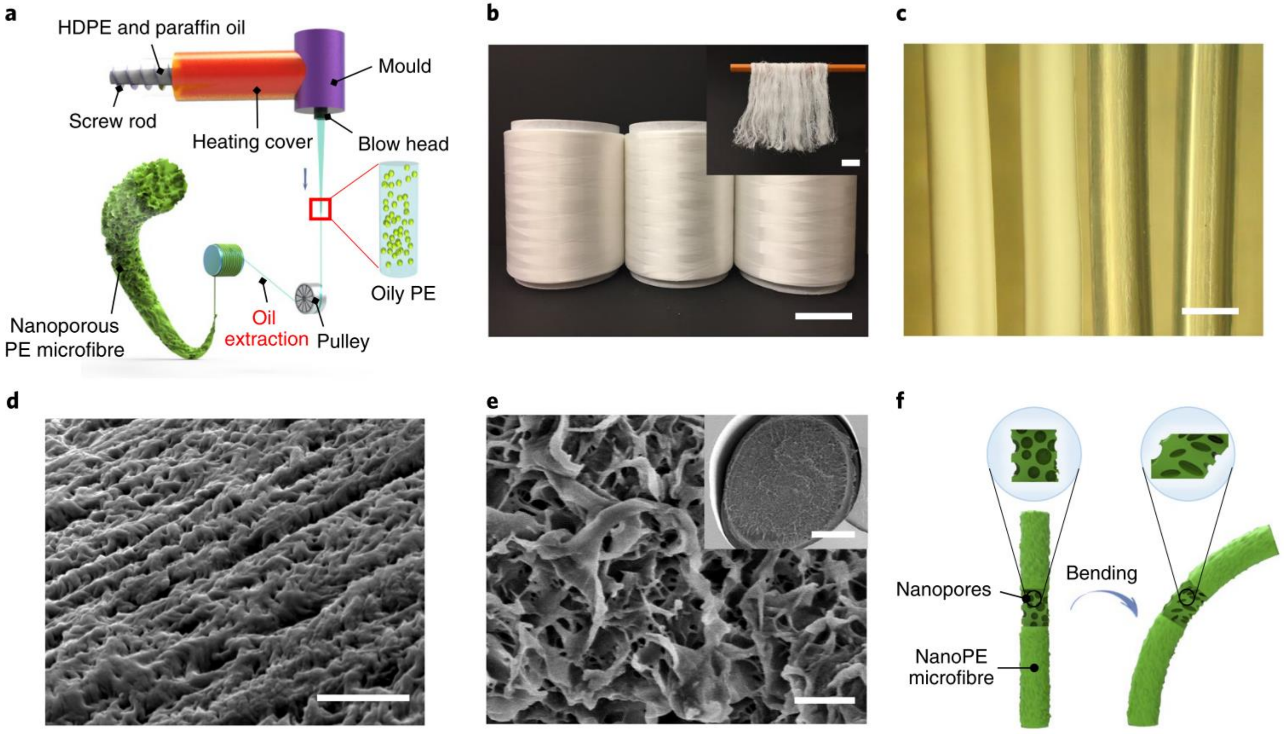


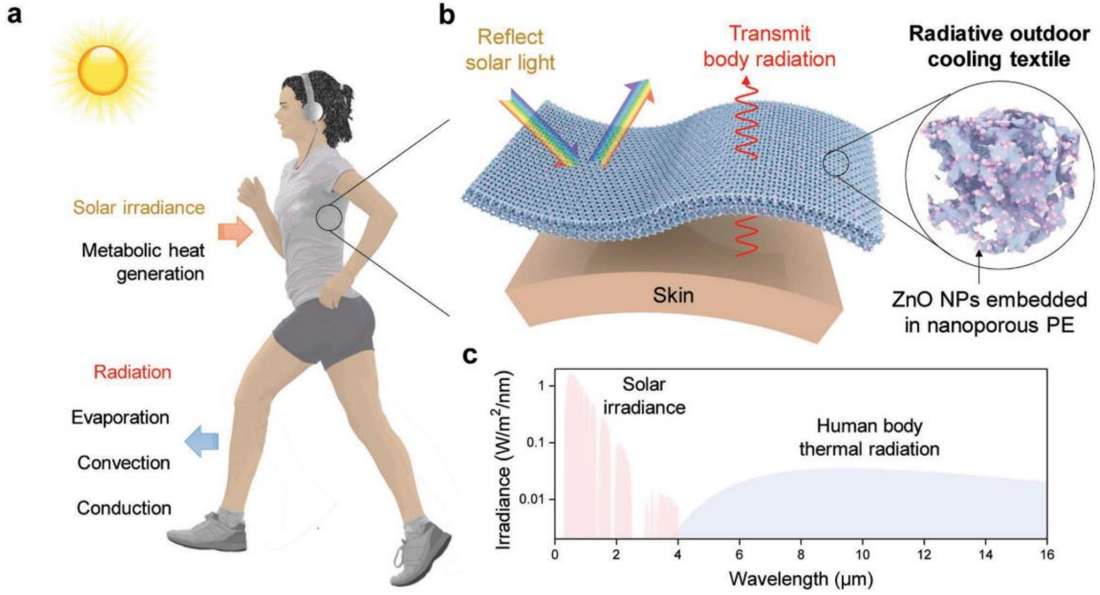
Application 3: Personal Thermal Management

NANOPOROUS POLYETHYLENE MICROFIBRES FOR LARGE-SCALE RADIATIVE COOLING, *Peng, Y.et al (2018). Nature Sustainability, 1, 105-112*

SUSTAINABLE POLYETHYLENE FABRICS WITH ENGINEERED MOISTURE TRANSPORT FOR PASSIVE COOLING , *Alberghini, M.et al (2021). Nat. Sustainability, 4, 715-724*

SPECTRALLY SELECTIVE NANOCOMPOSITE TEXTILE FOR OUTDOOR PERSONAL COOLING, *L. Cai et al Adv. Mater. 30, 1–7 (2018).*

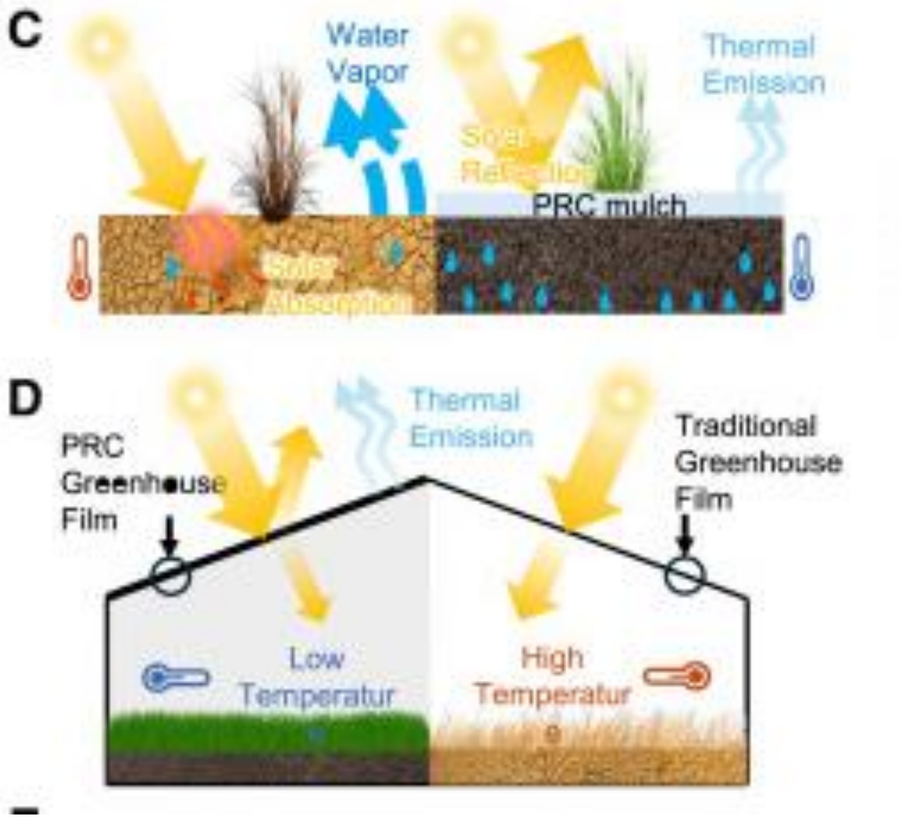




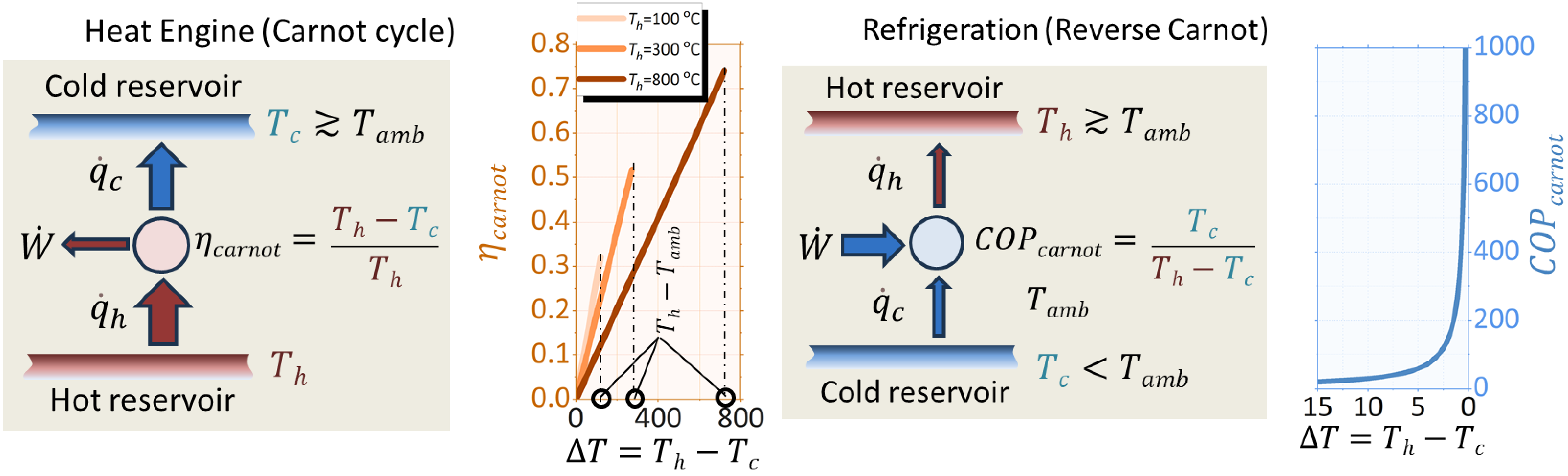
Application 4: Horticulture

Exploring real-world applications of passive radiative cooling for sustainability, Lin, Kaixin et al. *(2025)* Cell Reports Physical Science, 6, 2, 102445

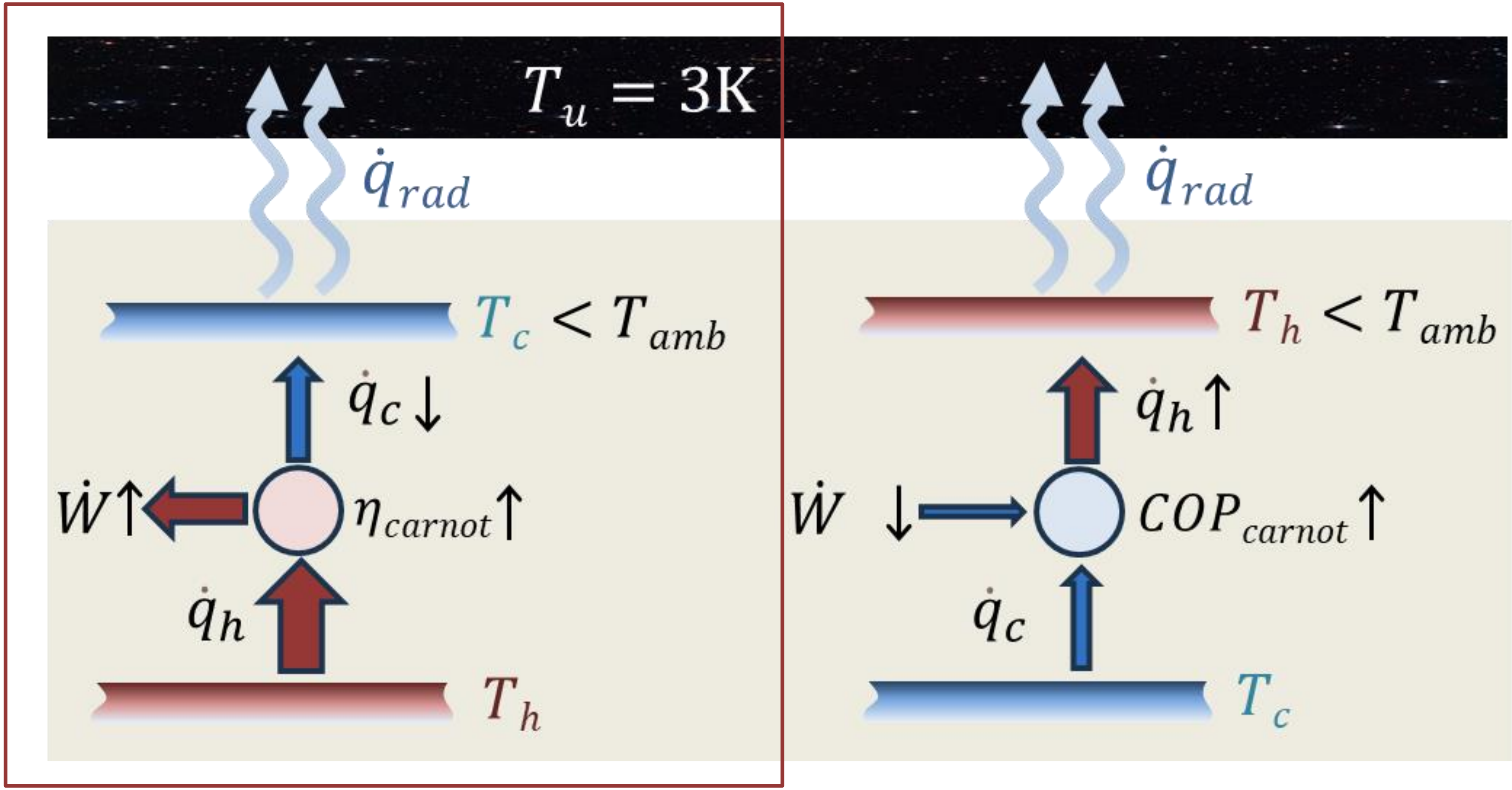
Enhancing food production in hot climates through radiative cooling mulch: A nexus approach, Wang, Chenxi et al. (2024) Nexus, Volume 1, Issue 1, 100002



Cooling to improve heat engine efficiency

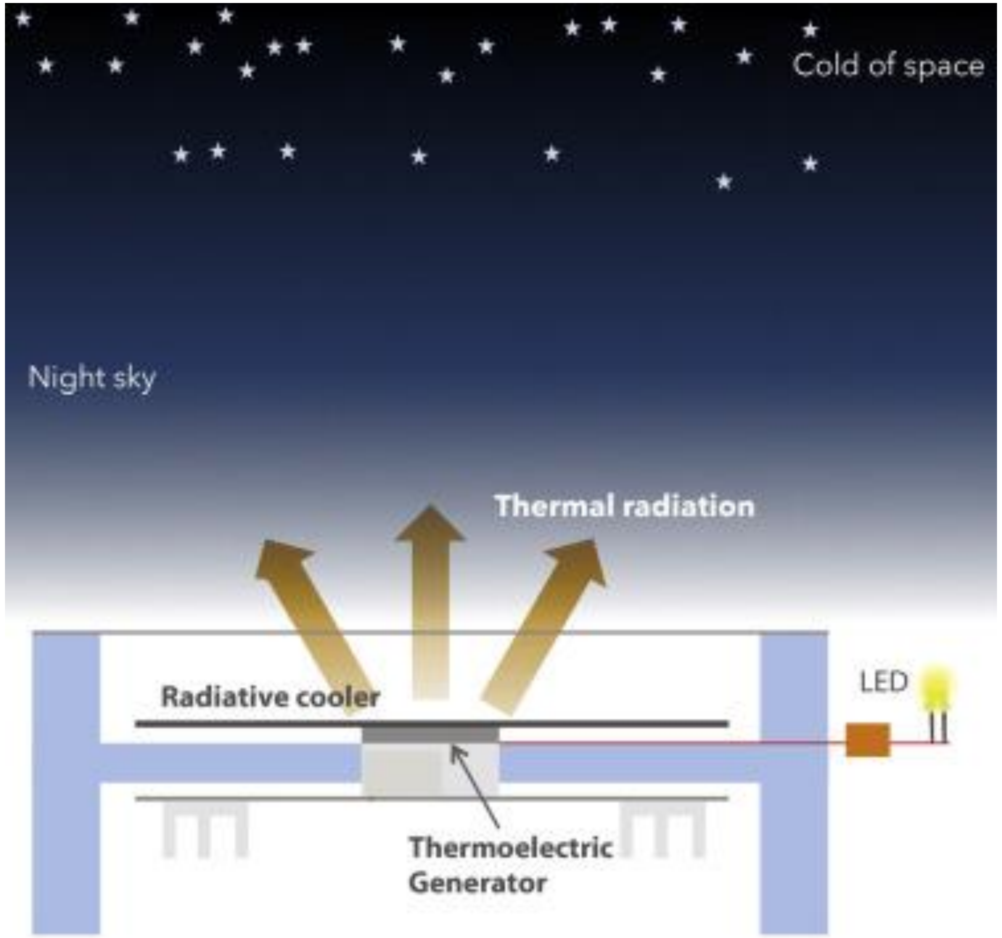


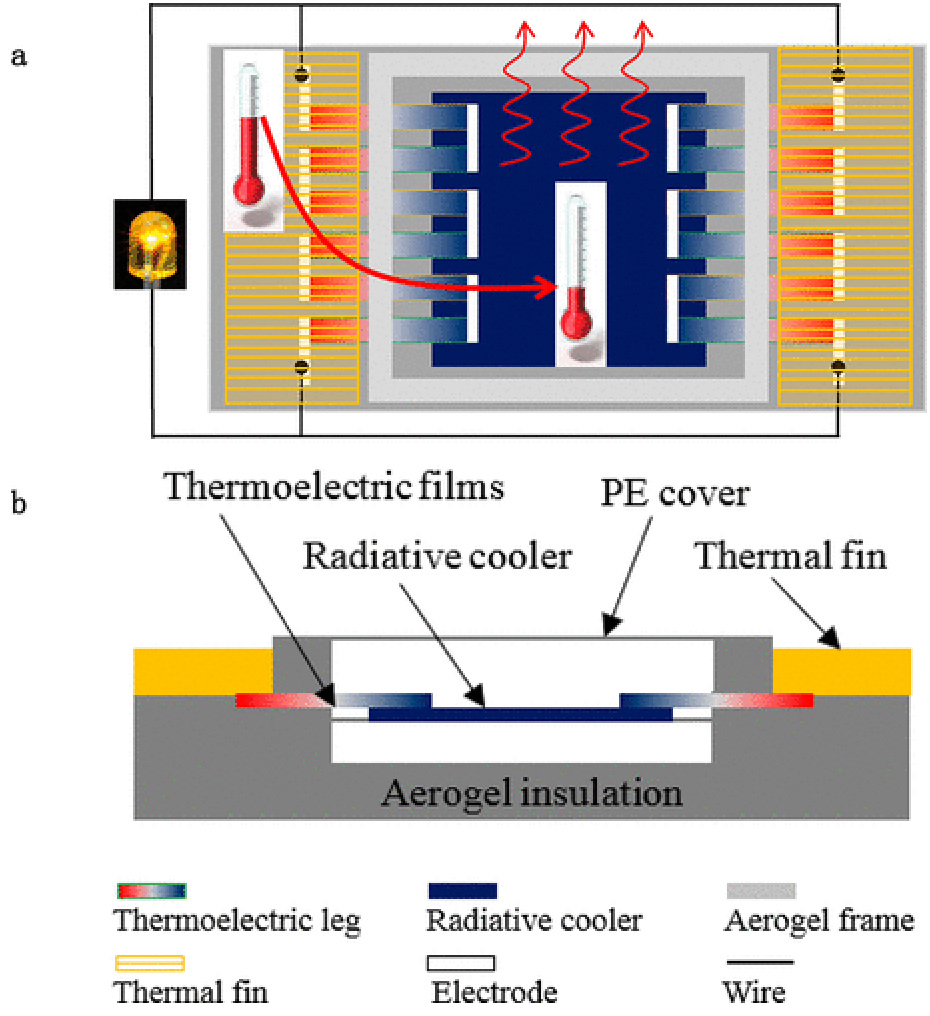
Cooling to improve heat engine efficiency



Thermoelectric generation

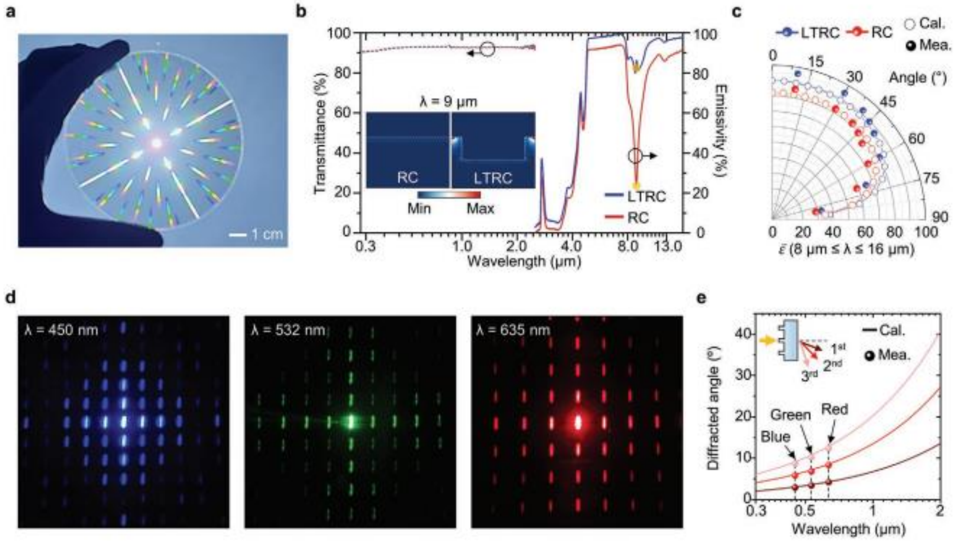
Thermoelectric Generator Using Space Cold Source *ACS Appl. Mater. Interfaces* 2019, 11, 37, 33941–33945
Generating Light from Darkness *Joule, Volume 3, Issue 11, 2679 - 2686*

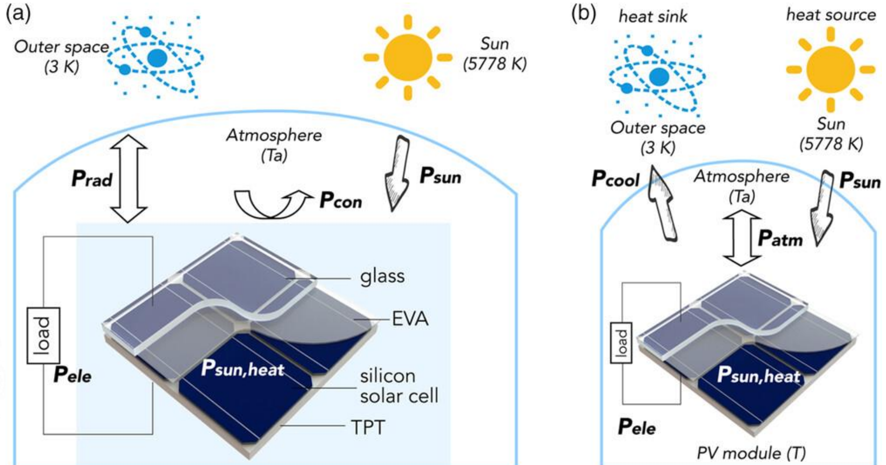


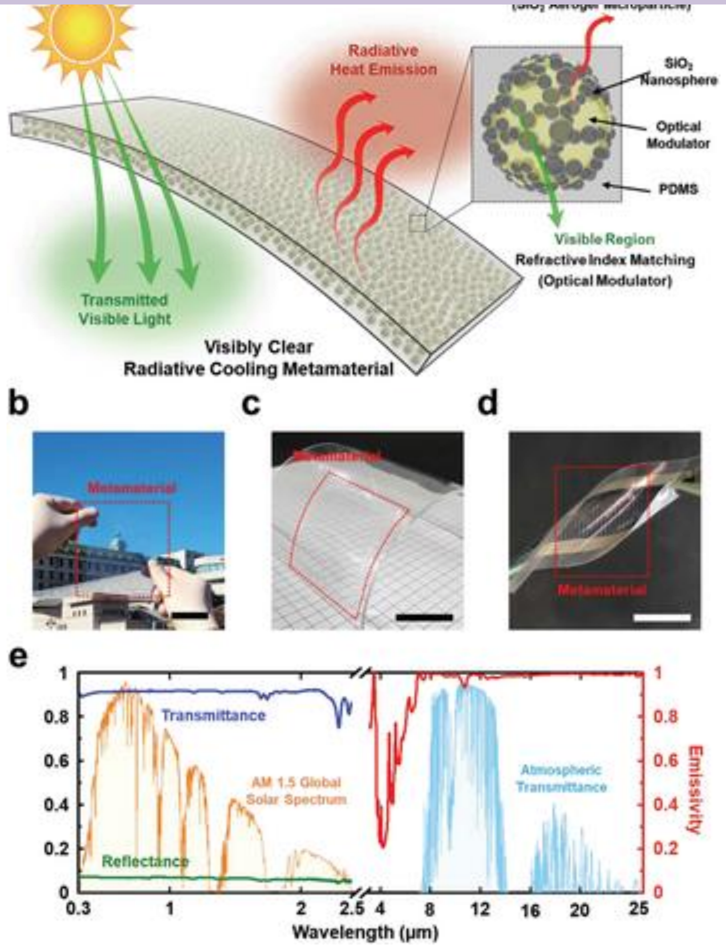


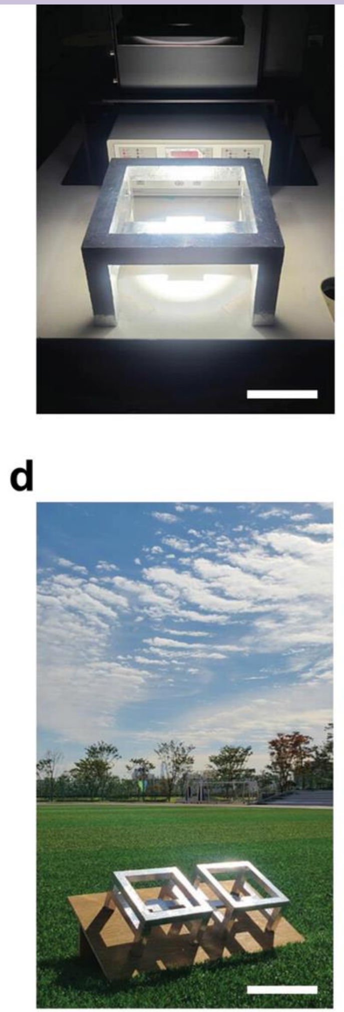
Passive cooling of Solar Cells

Performance analysis of enhanced radiative cooling of solar cells based on a commercial silicon photovoltaic module, Solar Energy, 176, 2018
A review on the integration of radiative cooling and solar energy harvesting, Materials Today Energy, 21, 2021

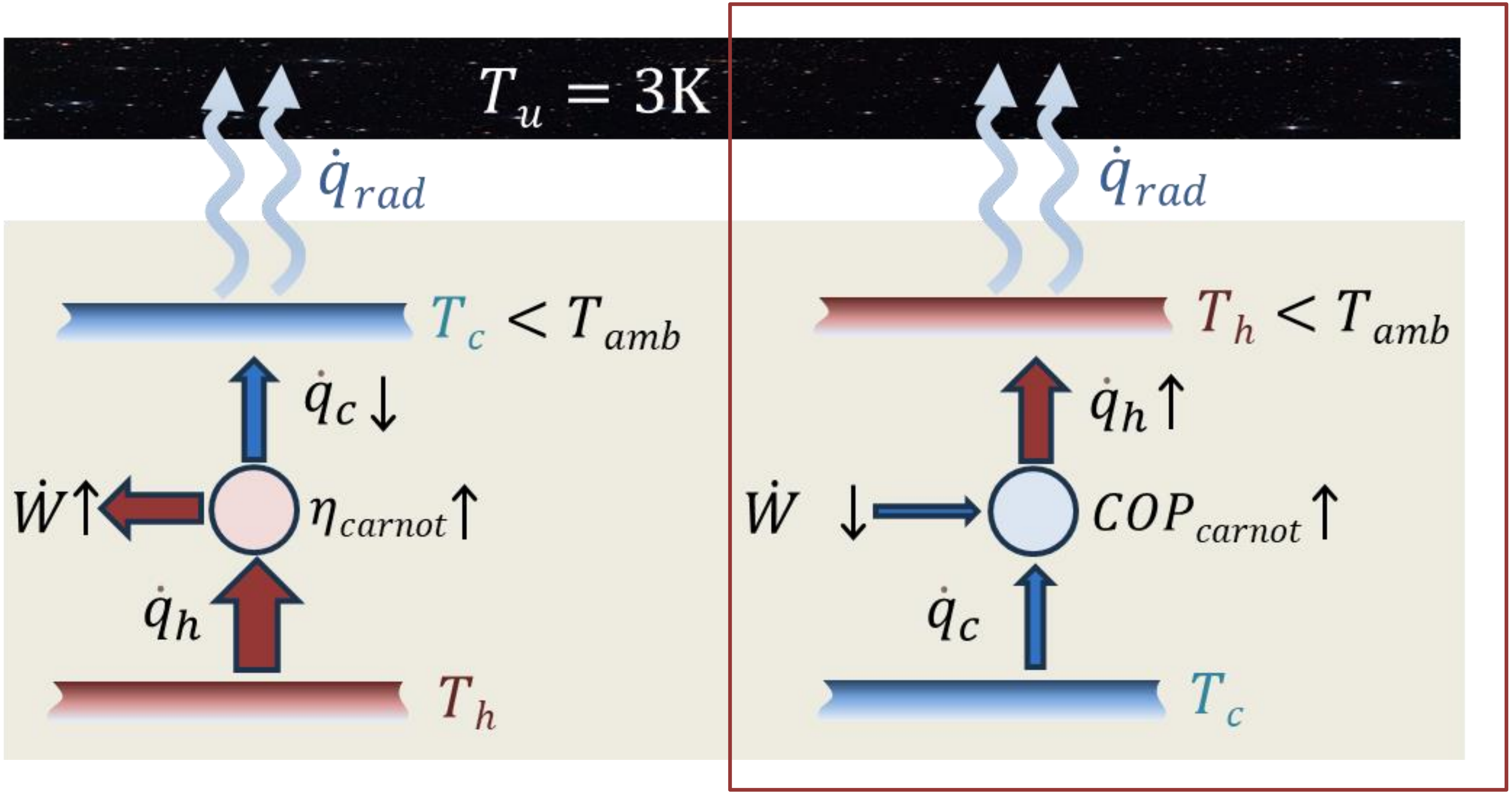






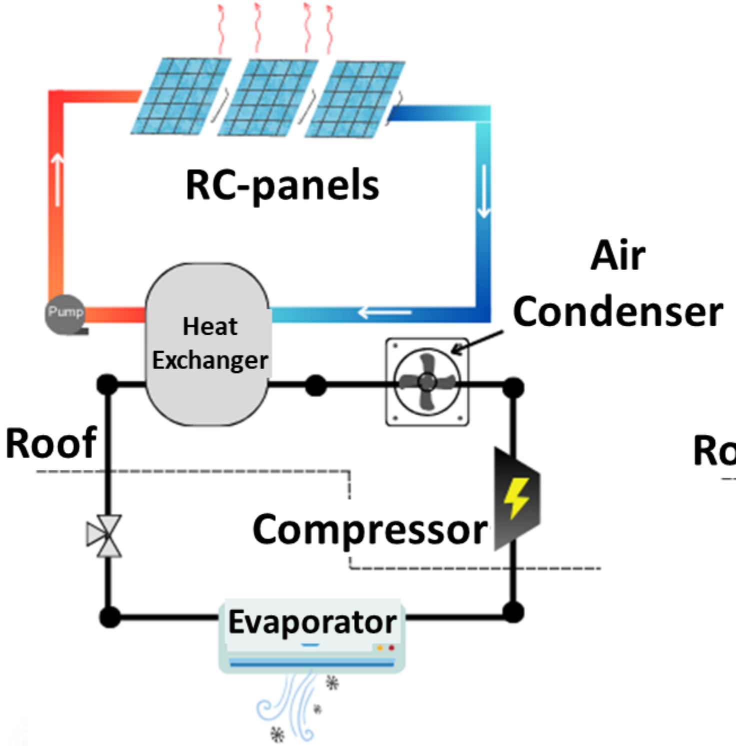


Cooling to improve refrigeration COP

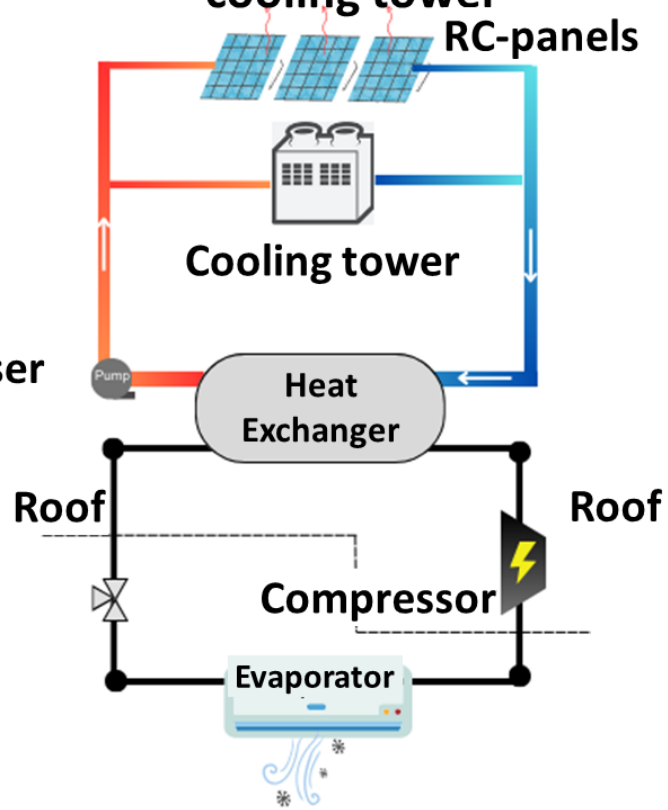


Integration with refrigeration engines

(A)
Sub cooling



(B)
Support to existing cooling tower



Property of Engie Crigen Lab

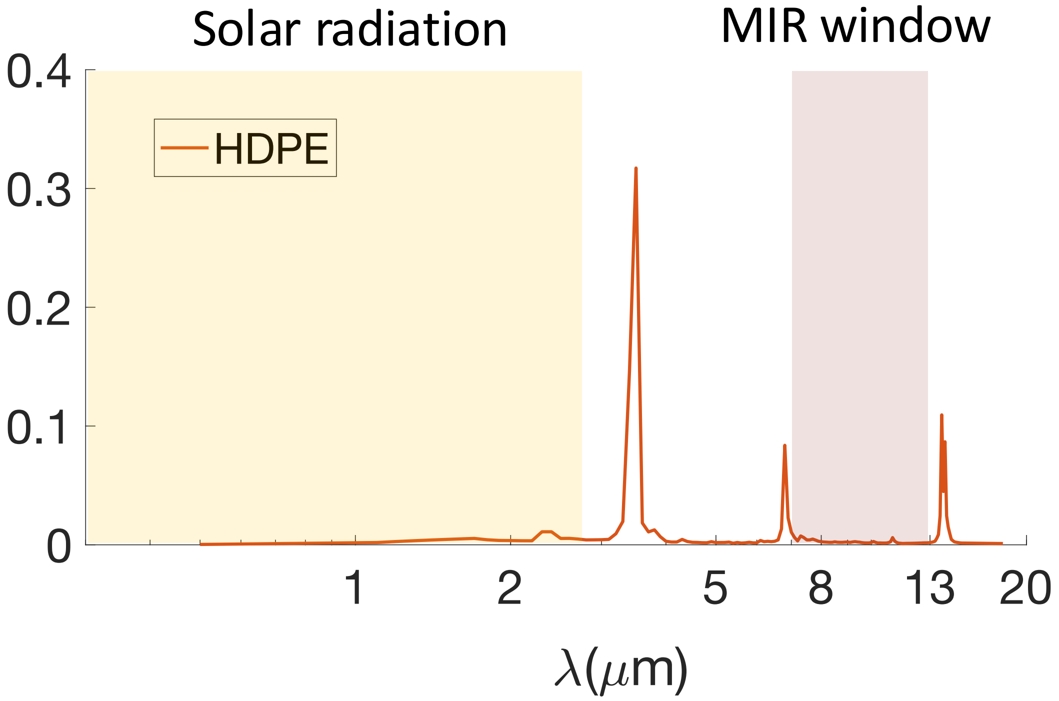
Pi-lab work in radiative cooling

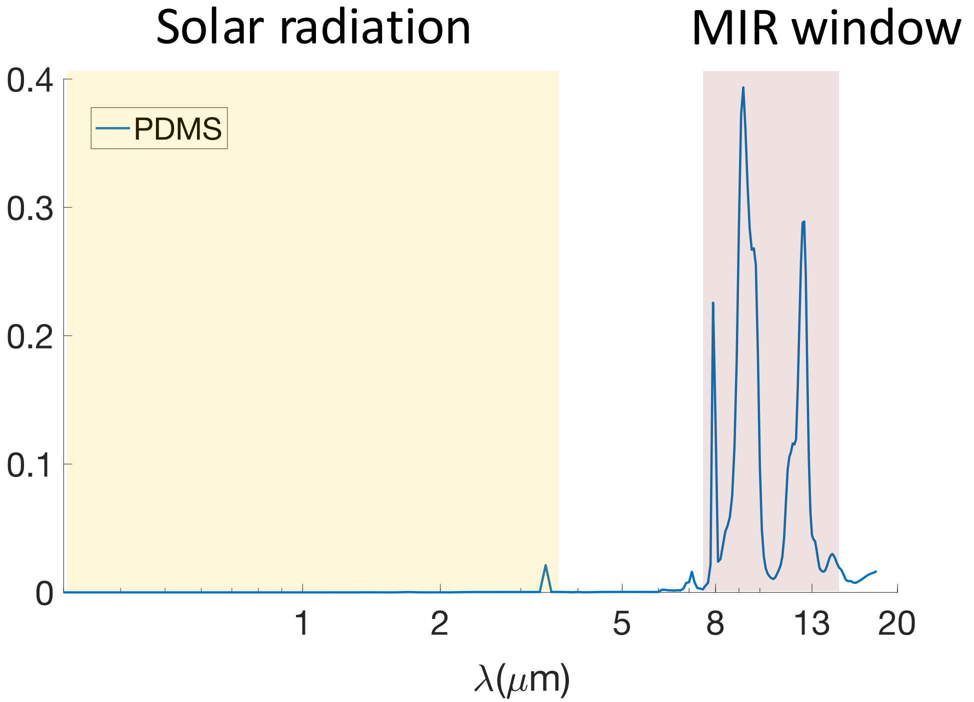
- Coatings
- Films
- Glass
- Self-adaptive systems
- Passive refrigeration systems
- Horticulture
- Heat and refrigeration engines
- Radiative cooling maps

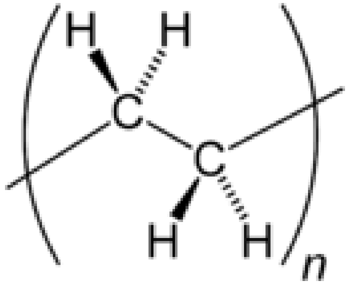
Definition of a “good” paint / coating /film

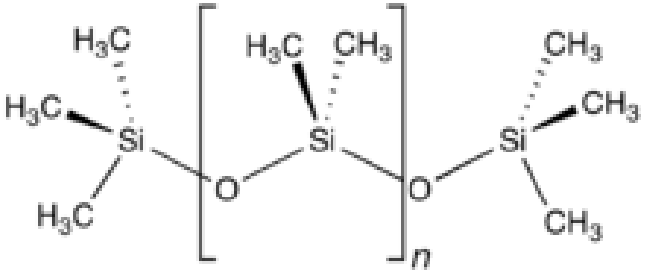
Desirable Characteristics
High cooling power
Low environmental impact (PFAS free, low VOC)
Mechanically durable (abrasion resistant, good tensile strength)
UV-resistant
Resist fouling (pollution, dust, chemicals in atmosphere)
Moisture resistance
Good adherence on most substrates (ceramics, glass, plastics, metals, concrete …)
Easily Scalable
Lightweight
Low cost
Adapt to ambient conditions

PolyCool: 1st Generation Coating



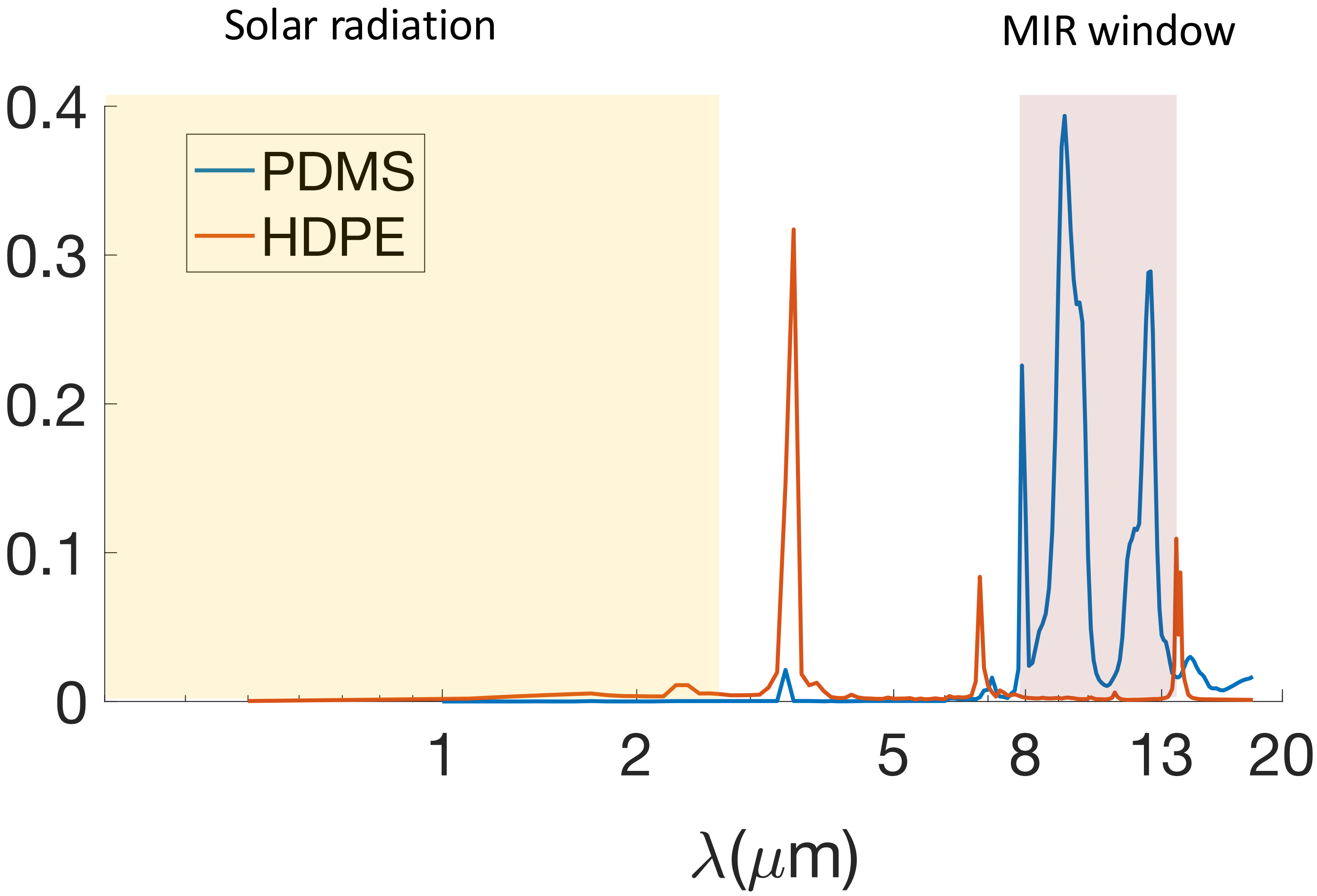




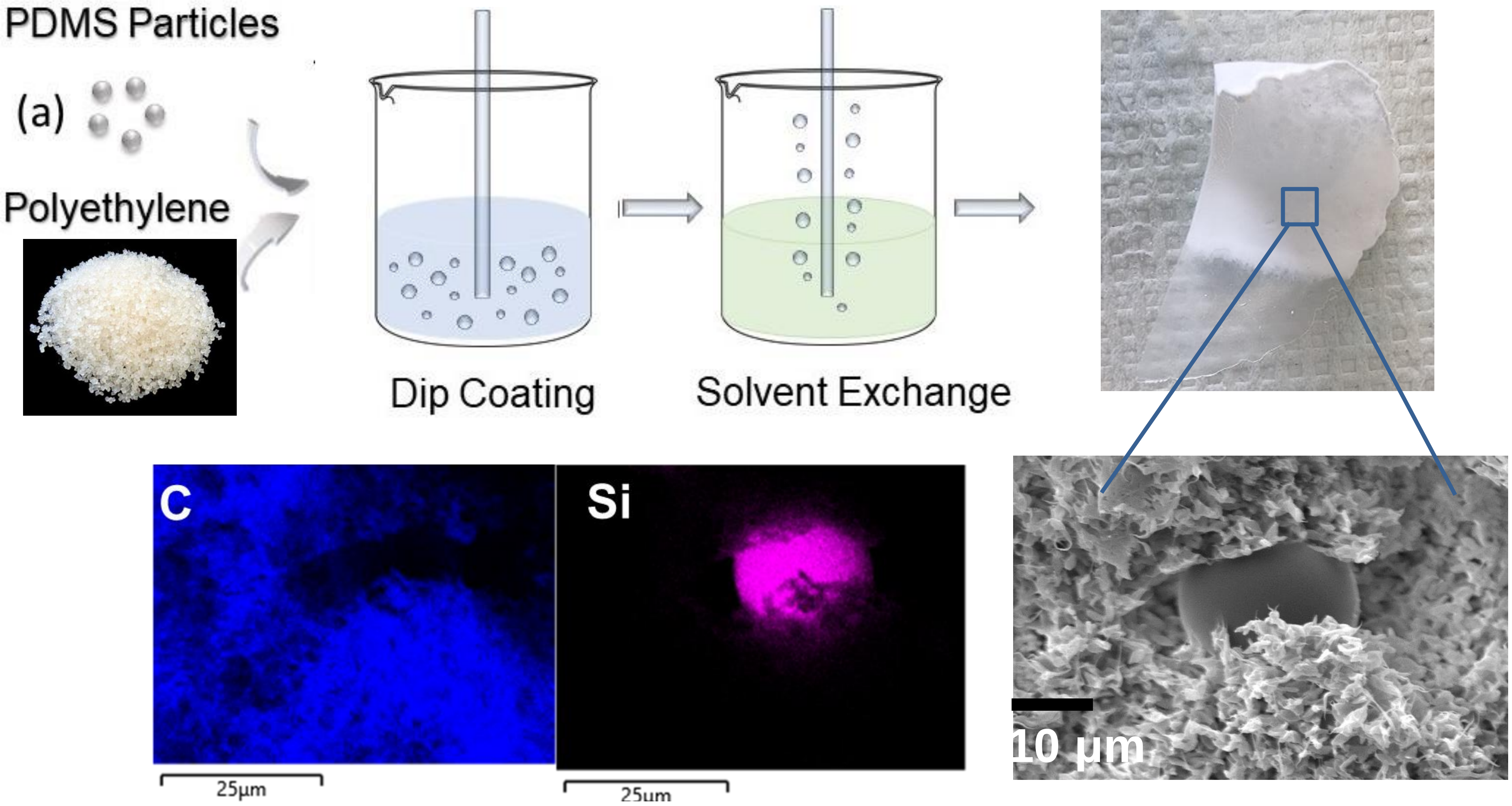


Lingxi L., Zulfiqar, U., Ramirez-Cuevas, F. V., Khan H., Santamouris M., Tiwari, M. K., Parkin, I. P., **Papakonstantinou, I.†** (2024). Radiative Cooling Coating by Using Porous PE with PDMS Nanoparticles, ScienceOpen Preprints, DOI: 10.14293/PR2199.000782.v1.

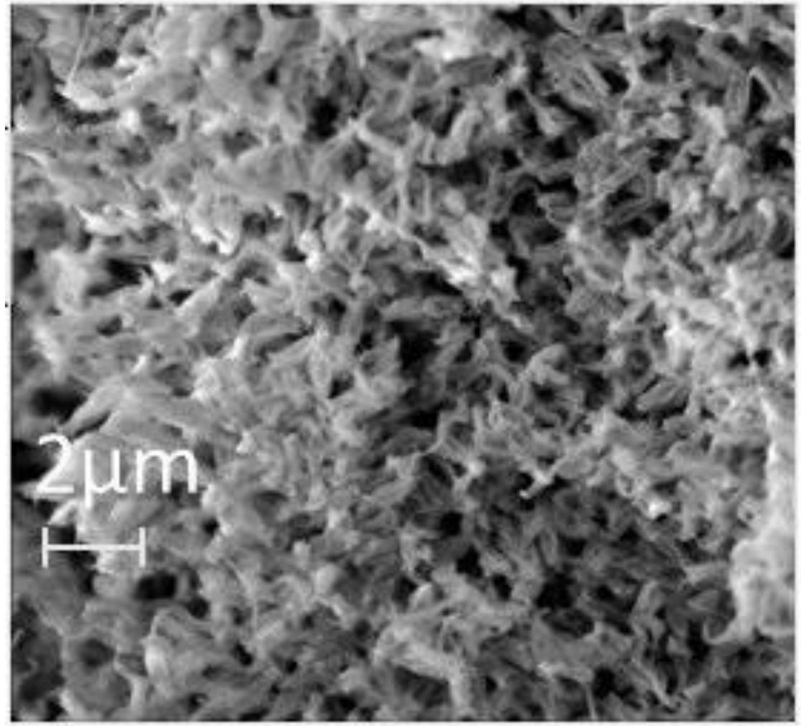
PolyCool: Static Coating

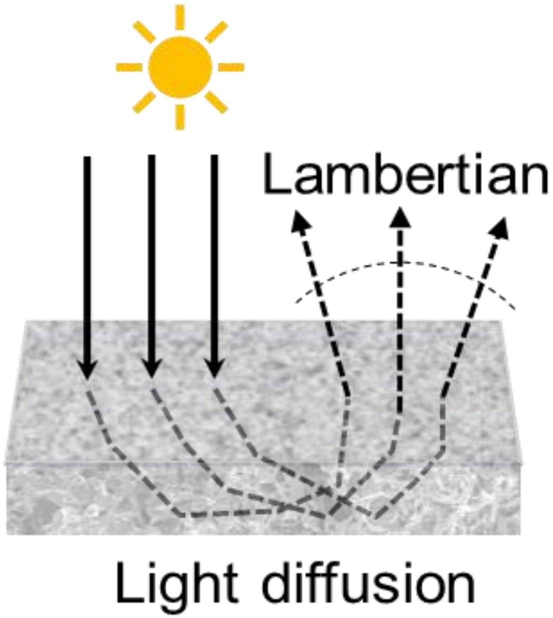


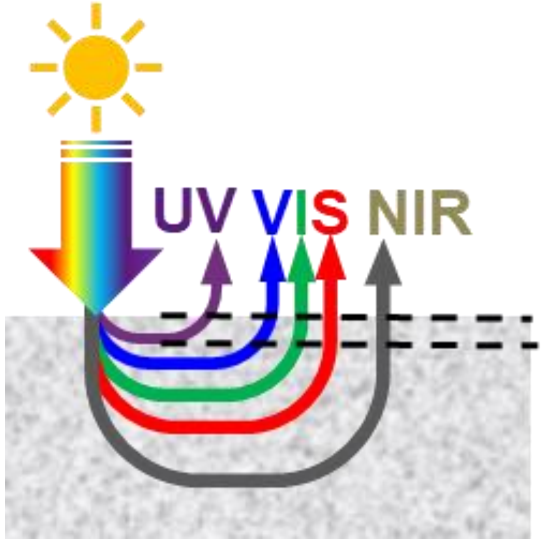
PolyCool Formulation



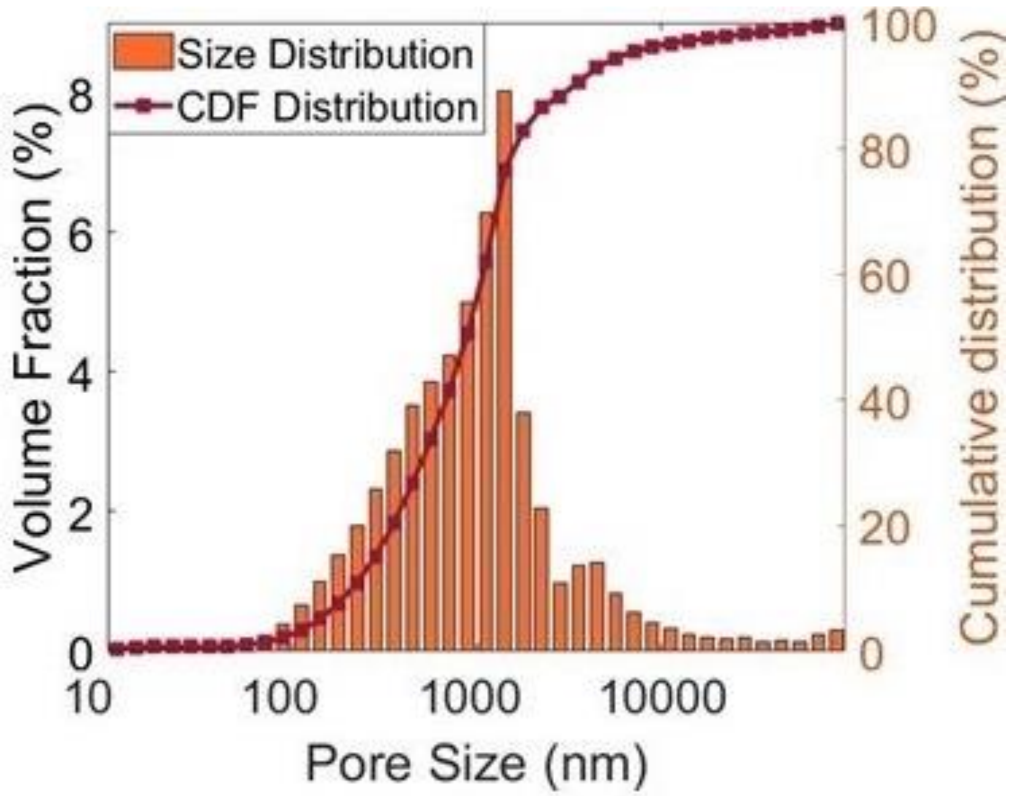
Why porous host?

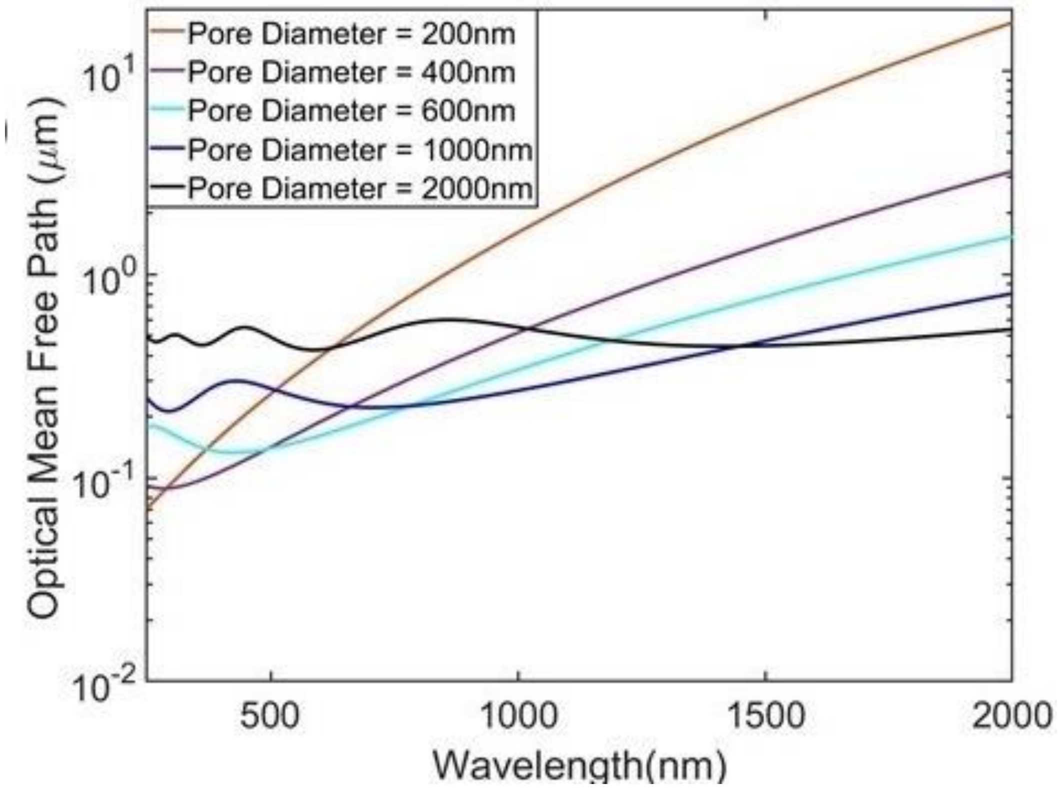




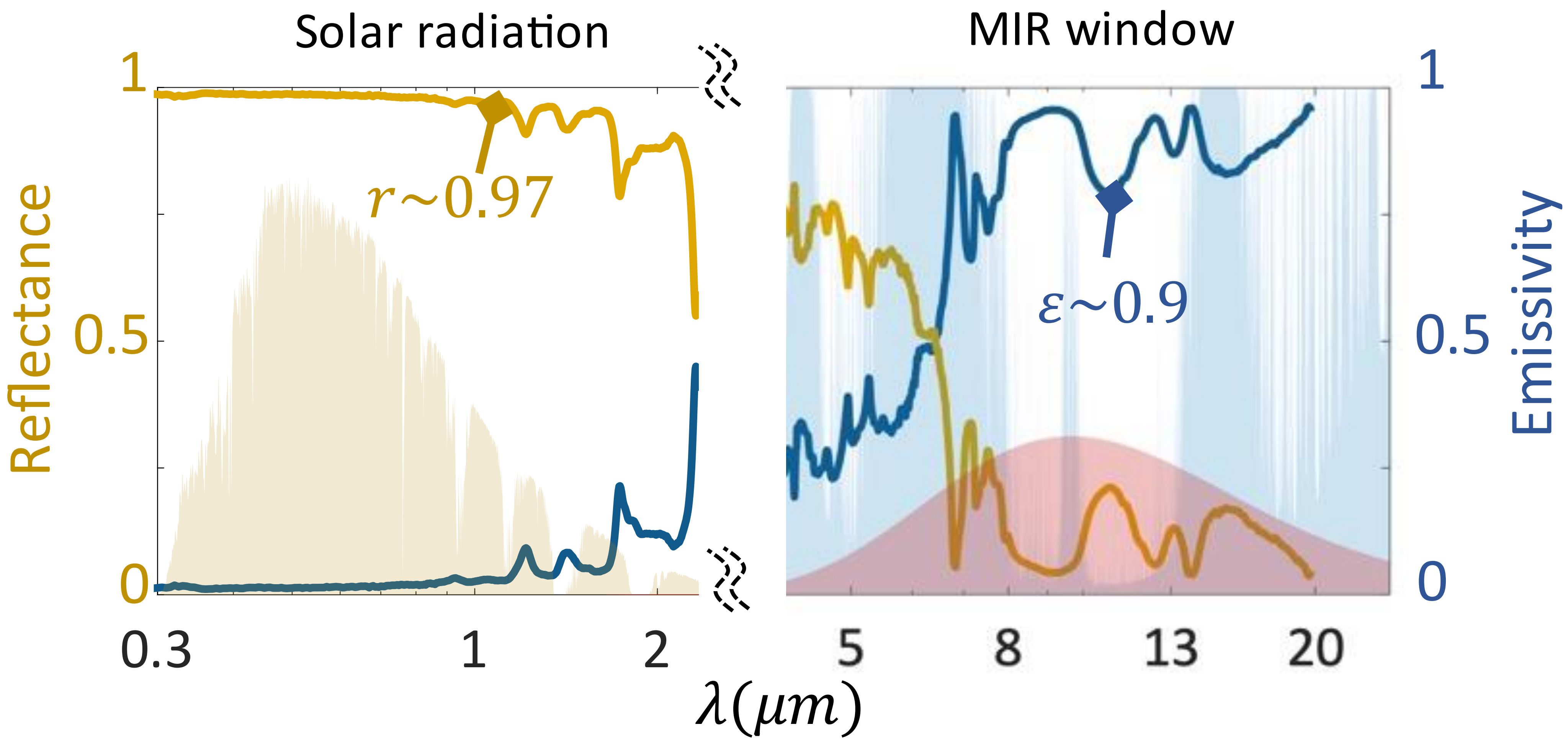


Porosity vs scattering

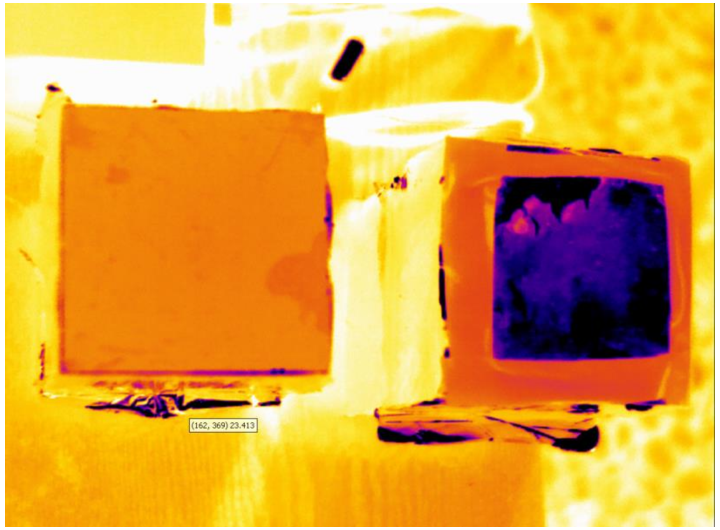


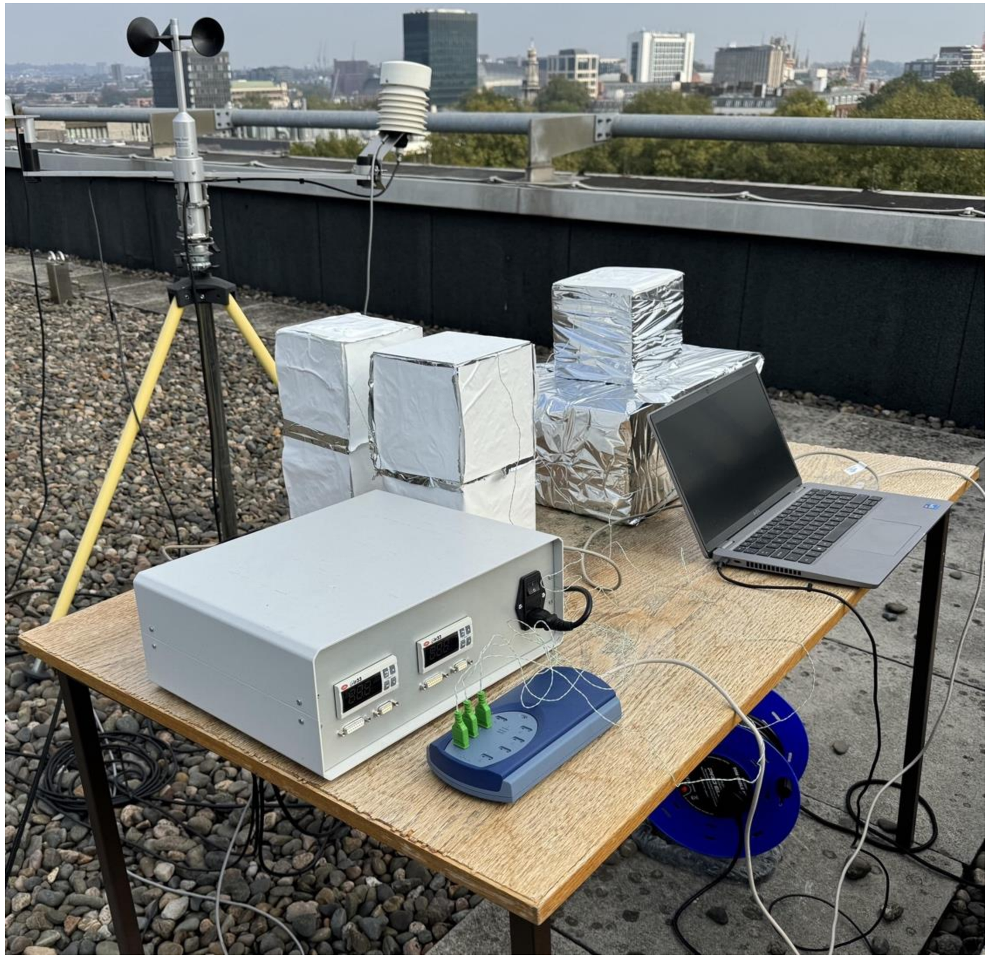


Optical Performance

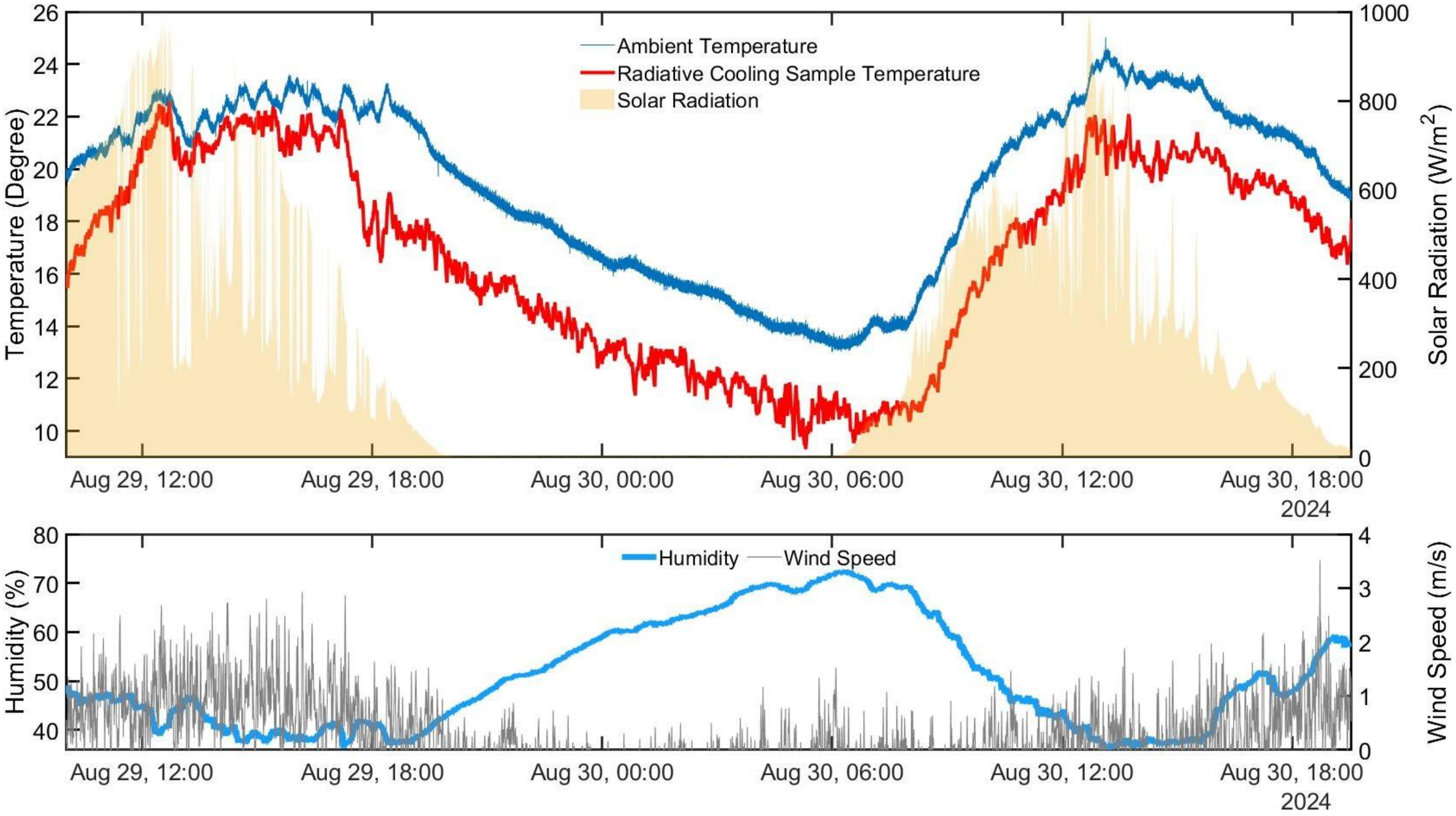


Outdoor tests - London





Outdoor tests – London (36h)



Next generation coatings – durable, durable and durable

- Water based for buildings
- Solvent based for vehicles
- Applied by spraying or brushing
- Durable – durable - durable

Abrasion resistance tests

Water repellency

Pilot studies

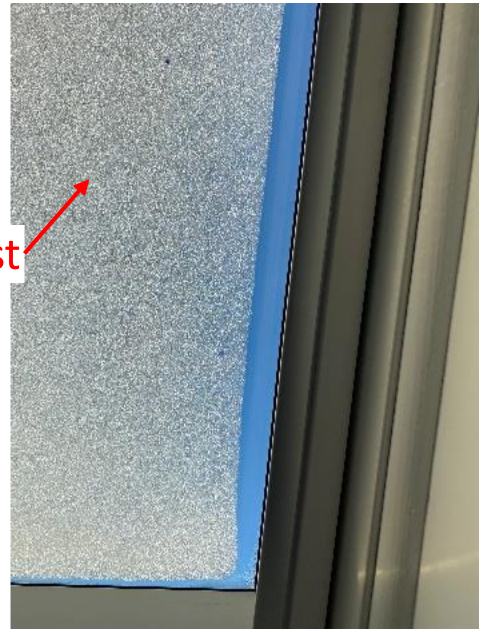
Madrid Oct 2024

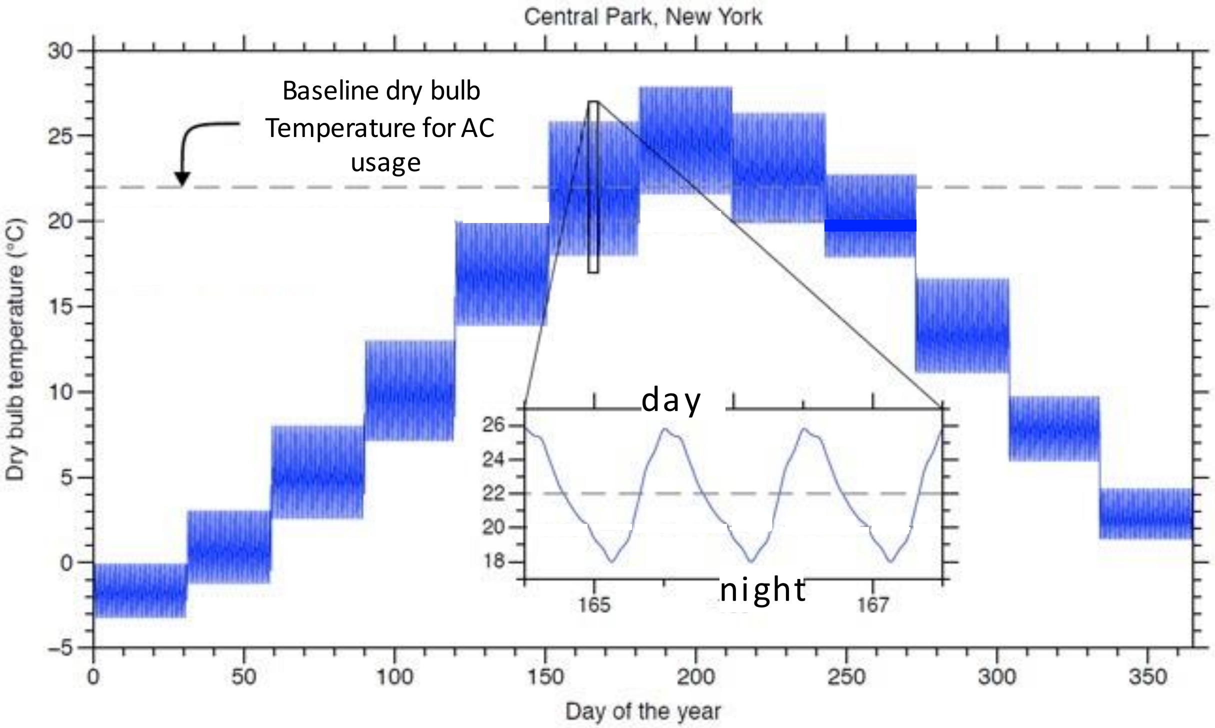
Property of Acciona

TFL Summer 2025

SINCERE: The second life of modern period architecture: Resilient and adaptive renovation towards net-zero carbon heritage buildings https://sincere-project.eu/

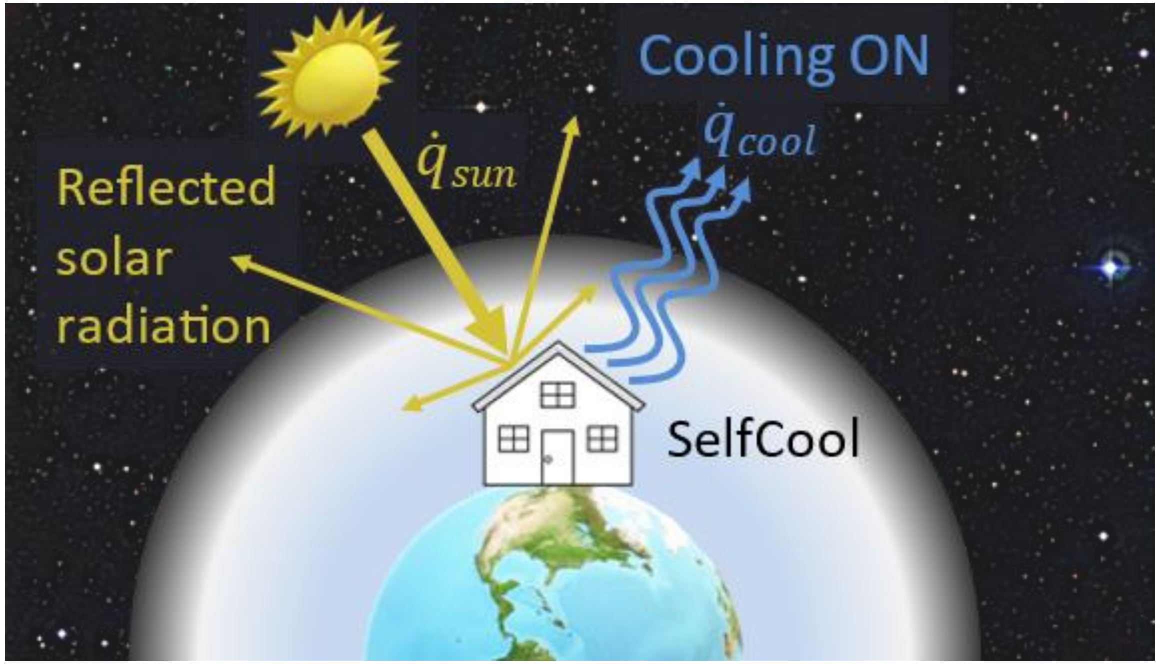
The need for tunable solutions



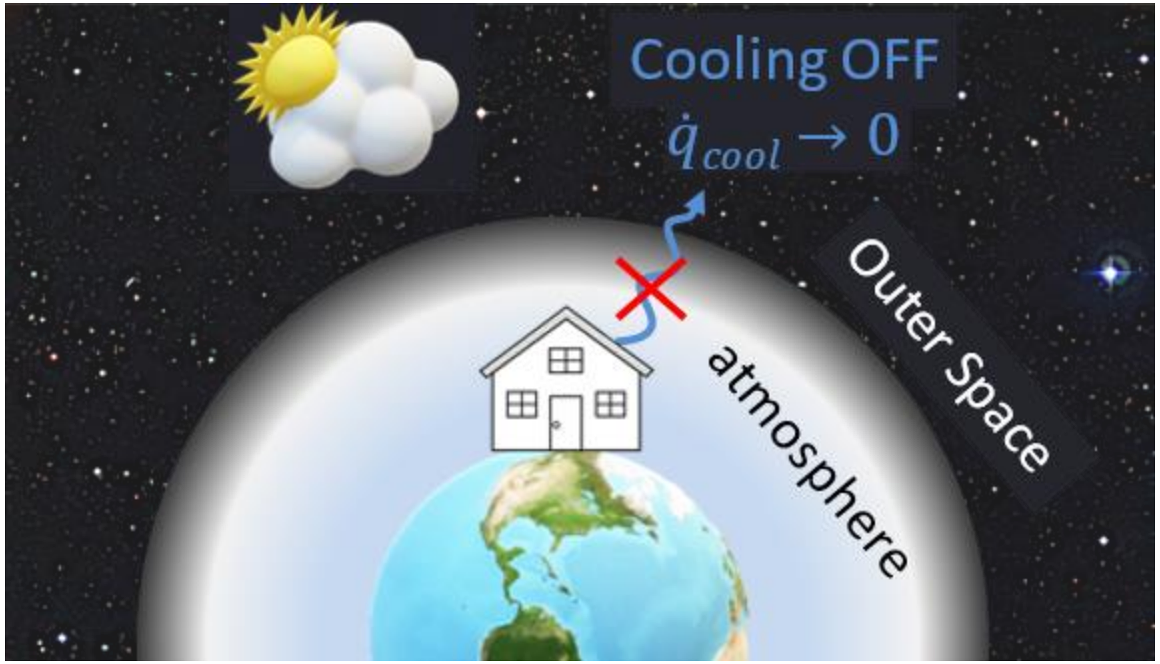


Emissivity control

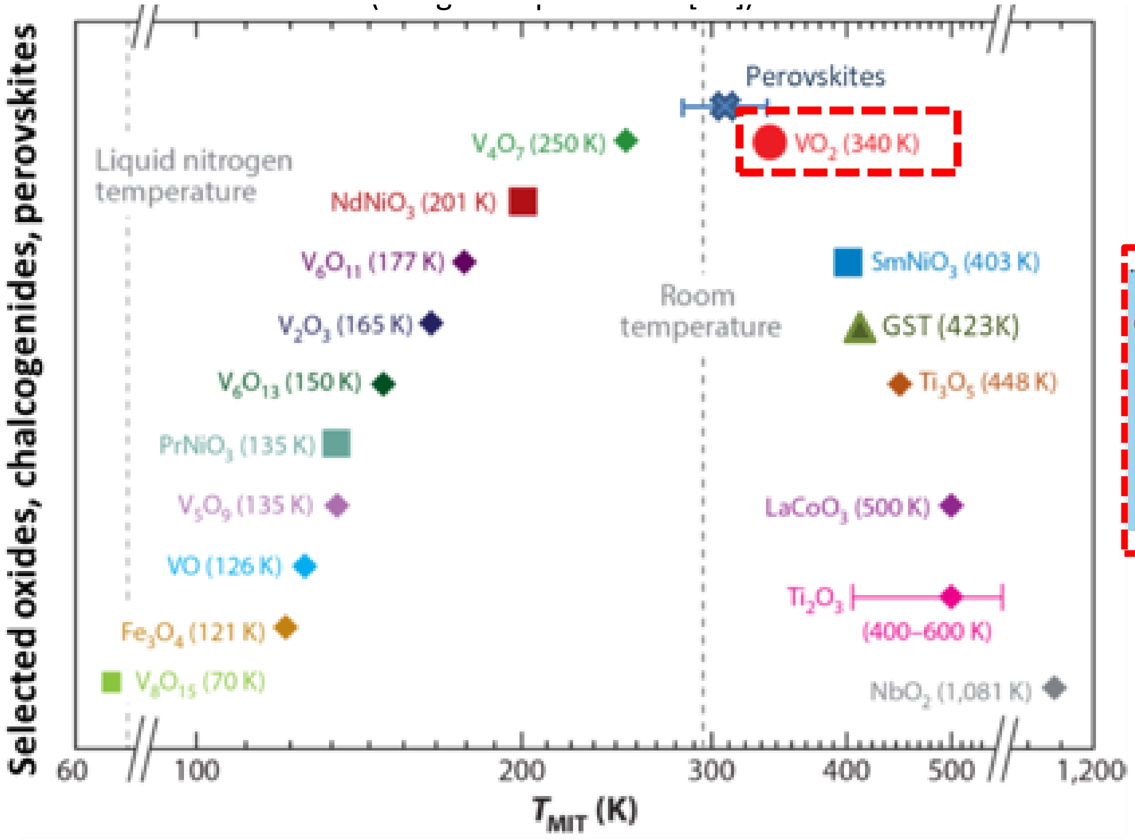
Summer



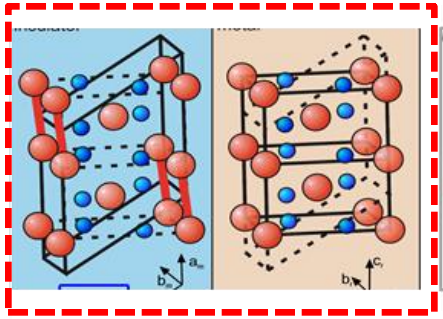
Winter

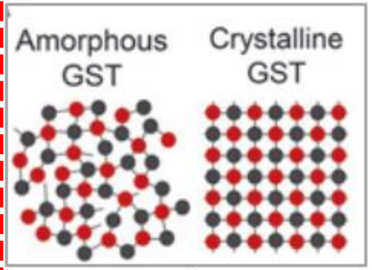


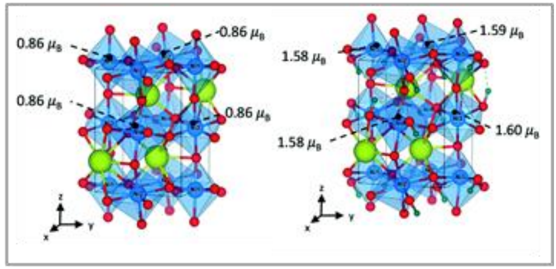
Phase change, thermochromic materials



VO$_2$

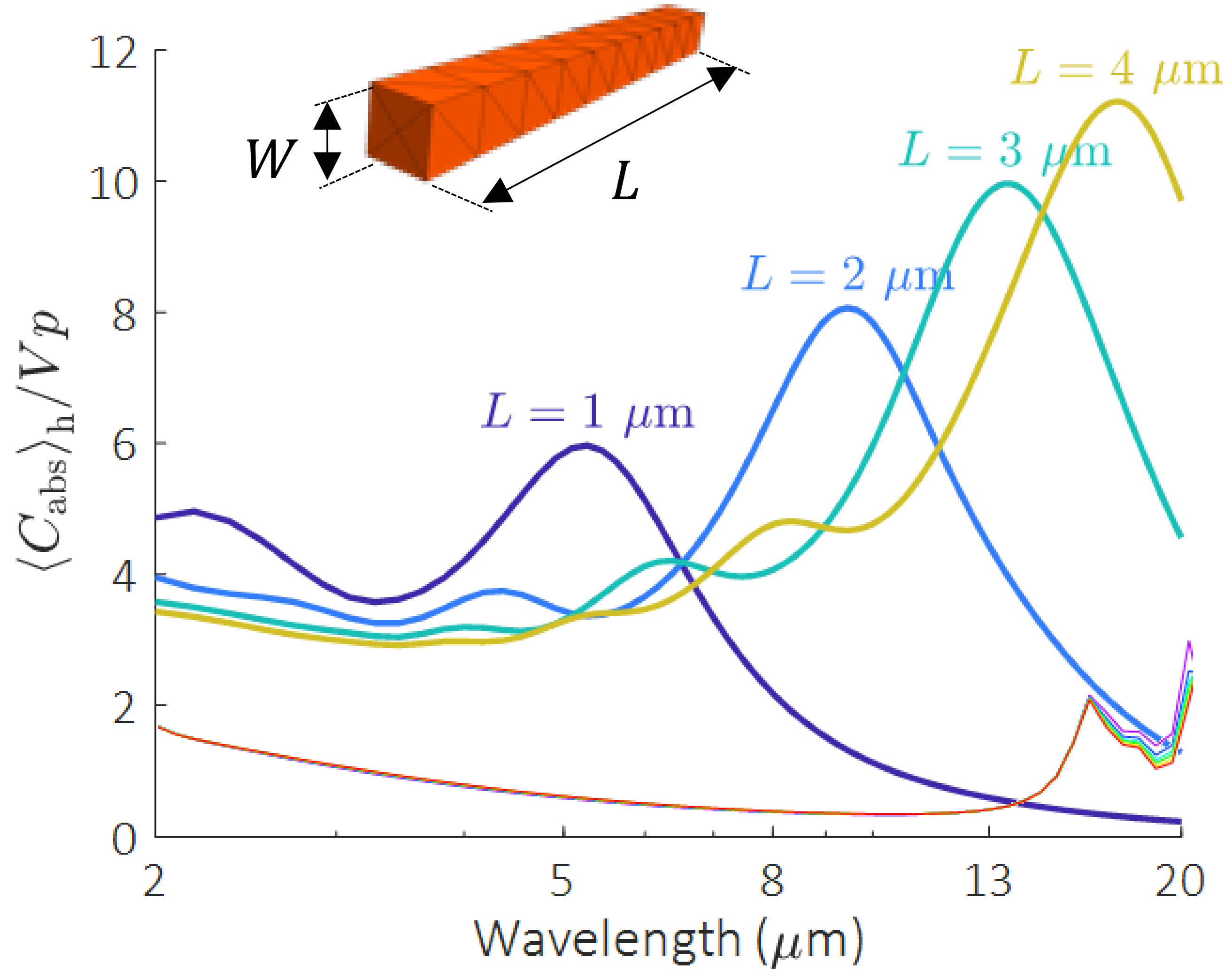






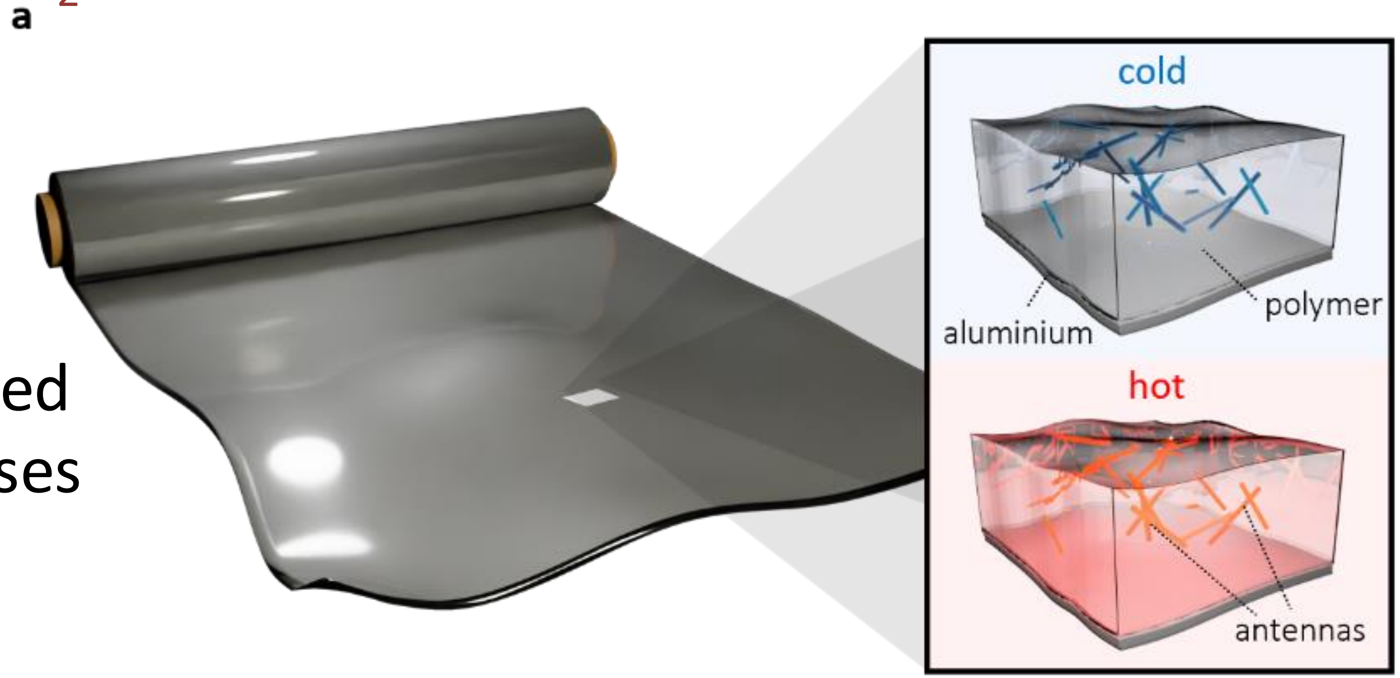
*Z. Yang, C. Ko, and S. Ramanathan, "Oxide electronics utilizing ultrafast metal-insulator transitions," *Annu. Rev. Mater. Res*. **4**1, 337–367 (2011).

IR antennas - tuneability



IR antenna composite foil for self-adaptive thermoregulation

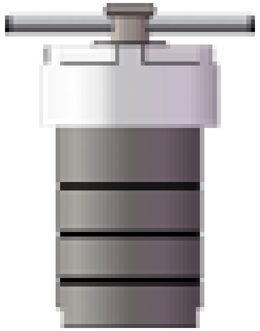
- Composite foil (PE polymer host + VO_2 thermal antennas)
- Substrate free, lightweight and flexible
- Very small amount of VO_2 synthesized with industrially compatible processes (hydrothermal)
- Scalable manufacturing with compression molding, roll-to-roll, injection molding



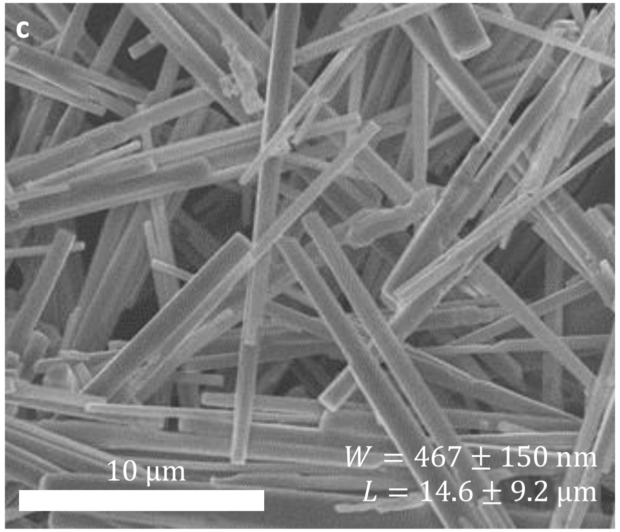
F. V Ramirez-Cuevas, K. L. Gurunatha, L. Lingxi, U. Zulfiqar, S. Sathasivam, M.K Tiwari, I. P. Parkin, and I. Papakonstantinou, " Infrared Thermochromic antenna composite for self-adaptive thermoregulation," ***Nat. Comms*, , 15, 9109 (2024).**

Self-adaptive Composite fabrication

Hydrothermal synthesis

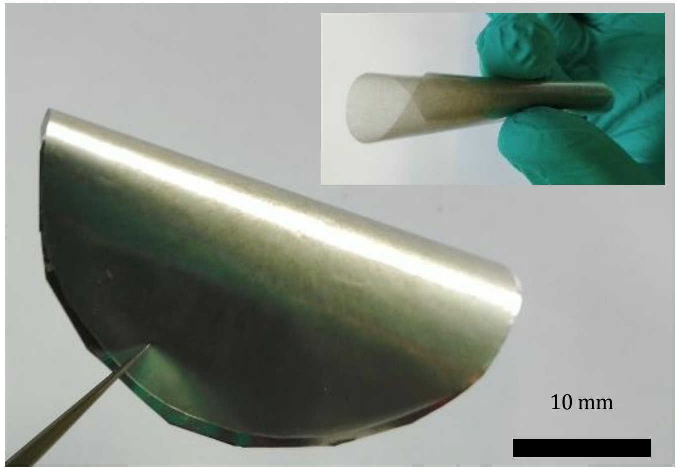


Thermochromic antennas

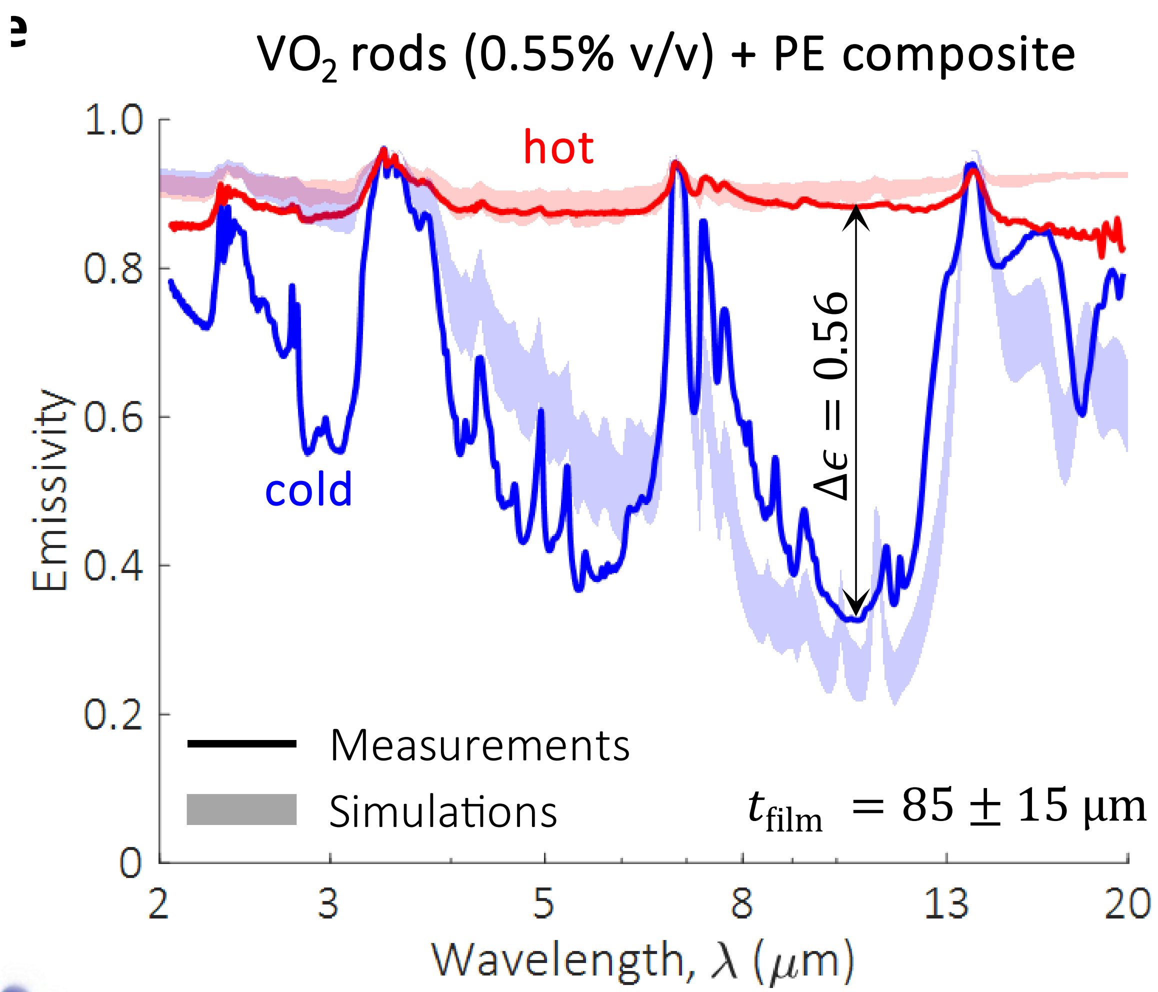


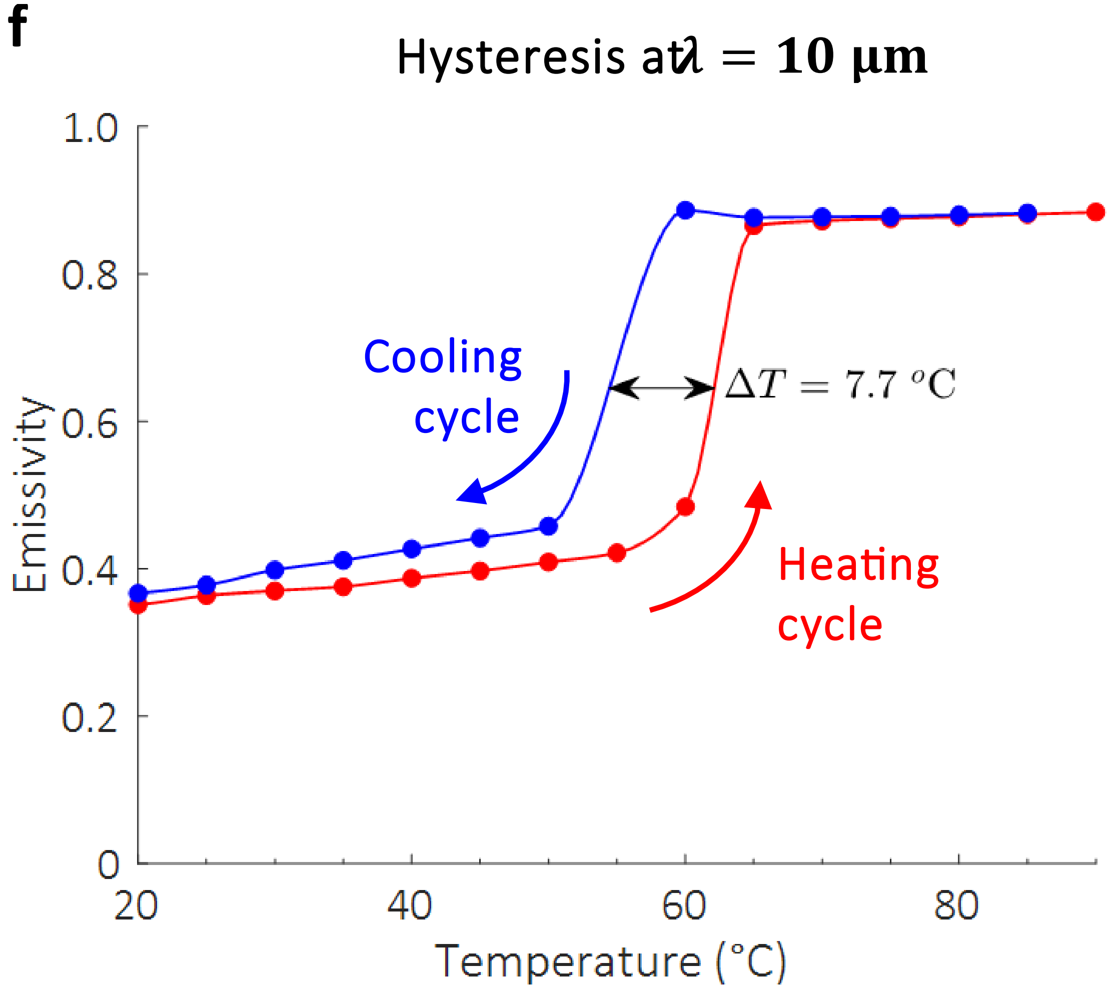
K. L. Gurunatha, S. Sathasivam, J. Li, M. Portnoi, I. P. Parkin, and I. Papakonstantinou, "Combined Effect of Temperature Induced Strain and Oxygen Vacancy on Metal-Insulator Transition of VO_2 Colloidal Particles," ***Adv. Funct. Mater.*** **30**, 2005311 (2020).

Compression molding

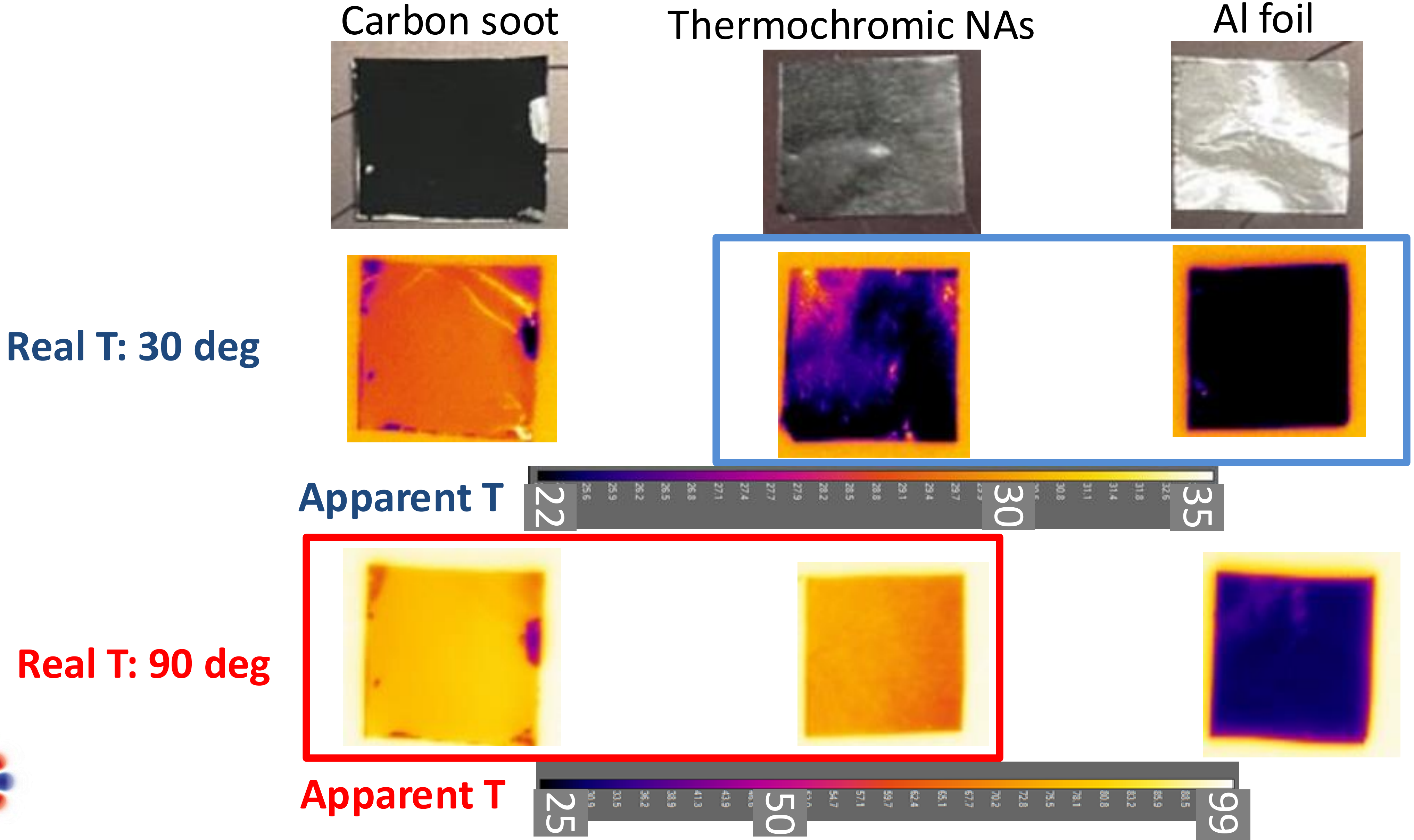


Self-Adaptive Emissivity – Experimental evidence

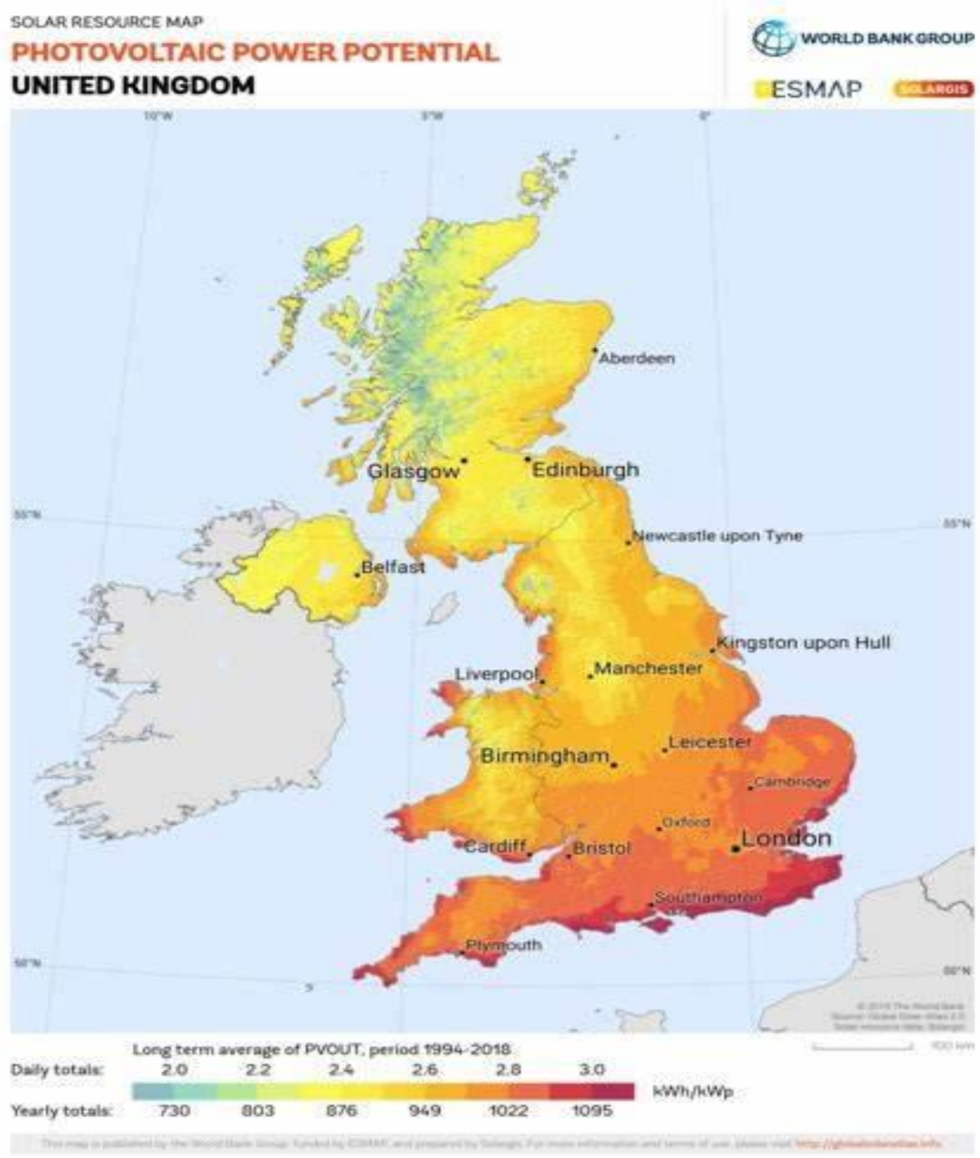


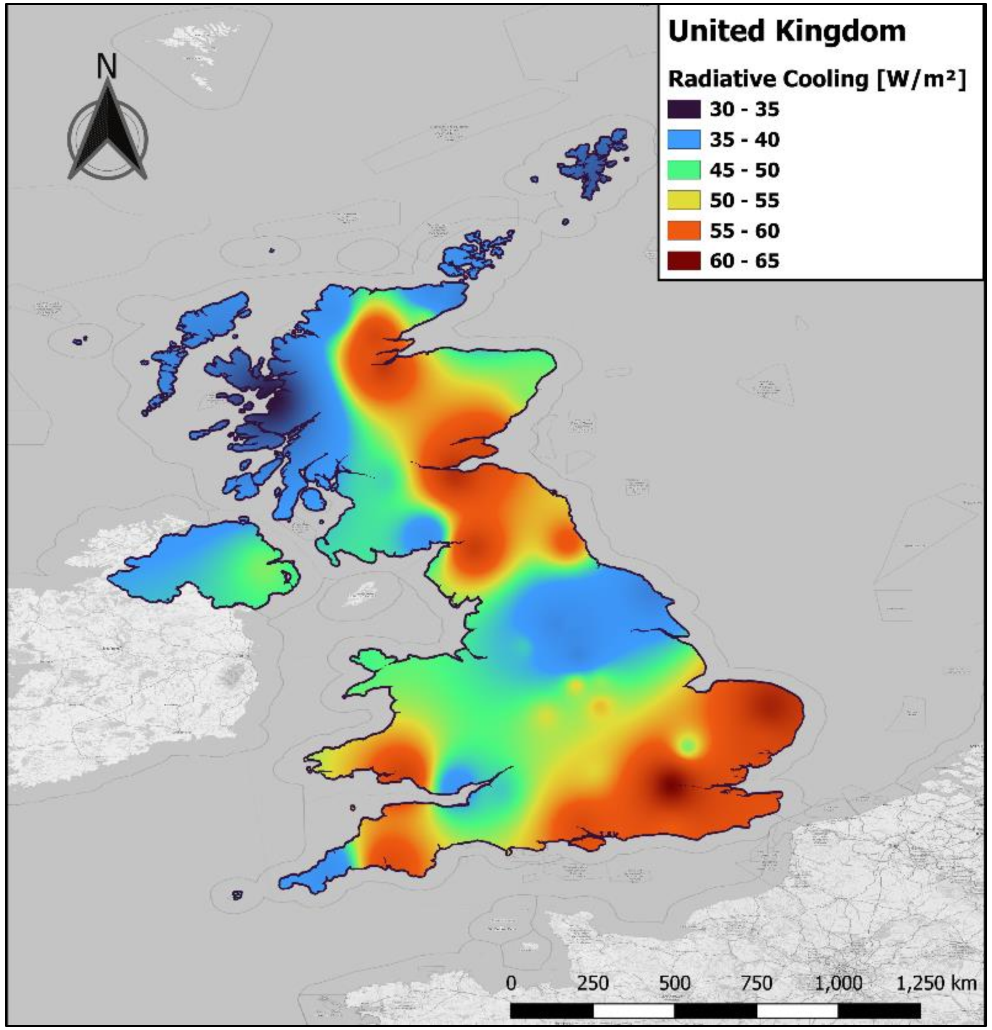


Self-Adaptive Emissivity – MIR images

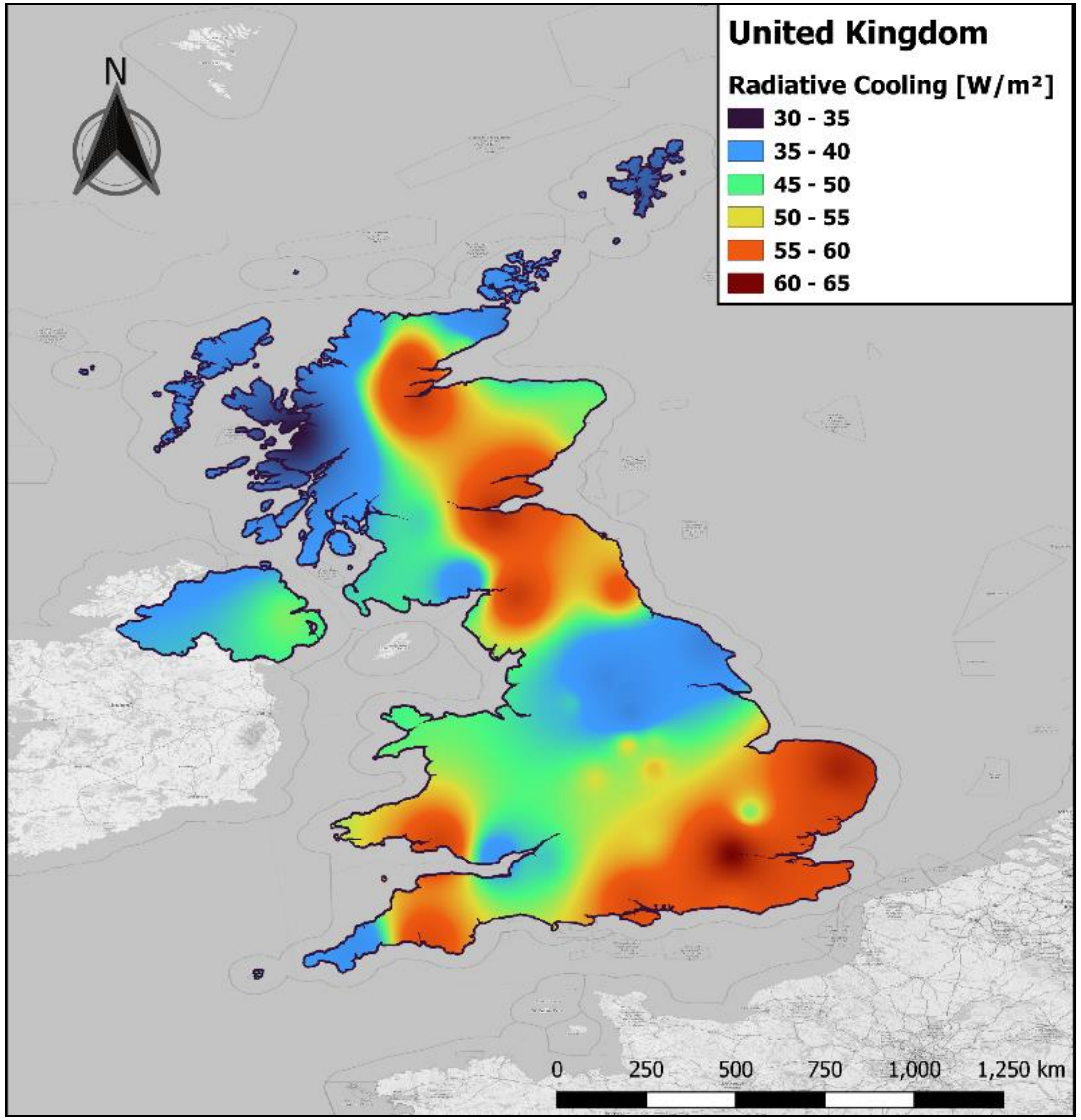


Solar Maps - Rad Cool Maps

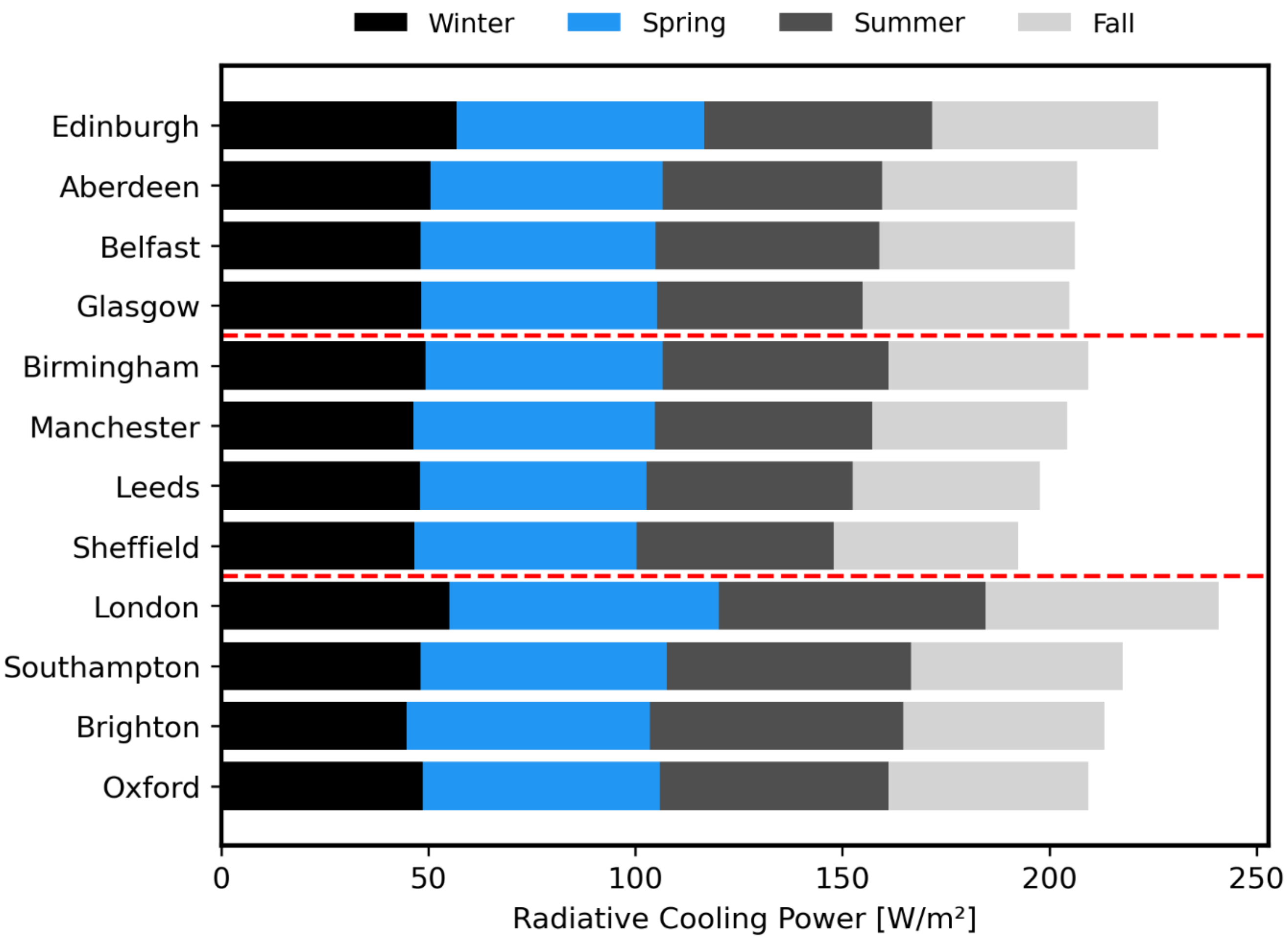




Radiative Cooling Maps (UK)



Radiative Cooling Potential UK



- North: Consistent cooling (47-60 W/m²), Edinburgh peaks at 56 W/m² in winter.
- South: Highest cooling in spring/summer, London reaches 65 W/m² in spring.
- Midland: Lowest cooling.
- Best Seasons: Spring most favorable, followed by summer, fall lowest potential.

Thank you for your attention!

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