

New metrology needs in a warming world

The four warmest years ever recorded occurred all after 2020, taking an **unprecedented toll in terms of human lives and economic losses**. Due to the energy-intensive nature of active cooling, UN and EU directives recommend “**utilising passive cooling to the fullest extent possible**” to curb electricity needs, accelerate F-gas dephasing, and defuse the spiralling loop of AC-driven urban heating.

Among passive cooling technologies, the emerging class of **radiative cooling materials** holds promise as a **sustainable and electricity-free** thermal management strategy able to **expel heat from our planet** rather than dumping it into the environment. Possible applications span across building and vehicle cooling, medicine and food preservation, thermal management of data centres, photovoltaic cells or electrical cabinets, thermoelectric generation and freshwater harvesting from air.

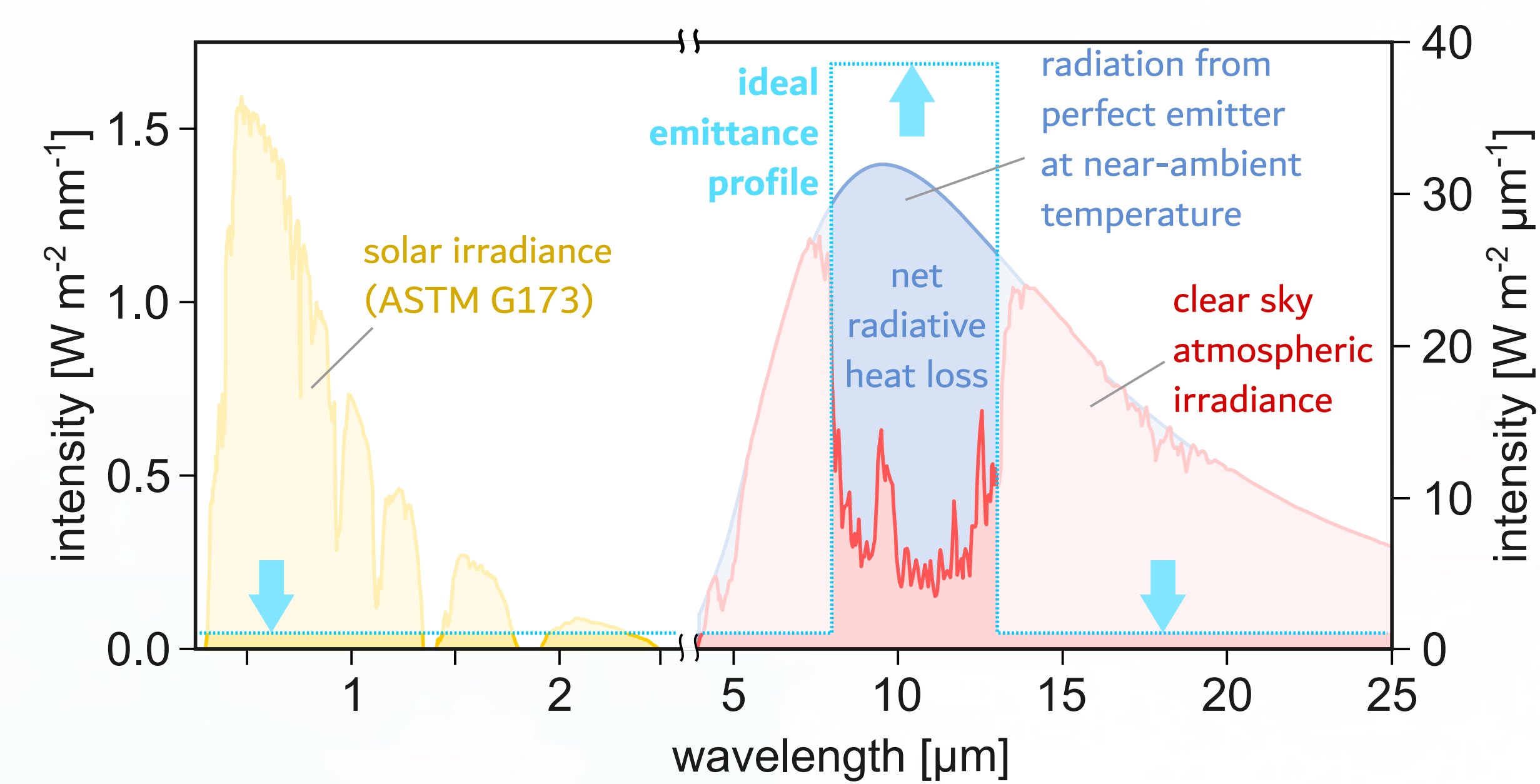
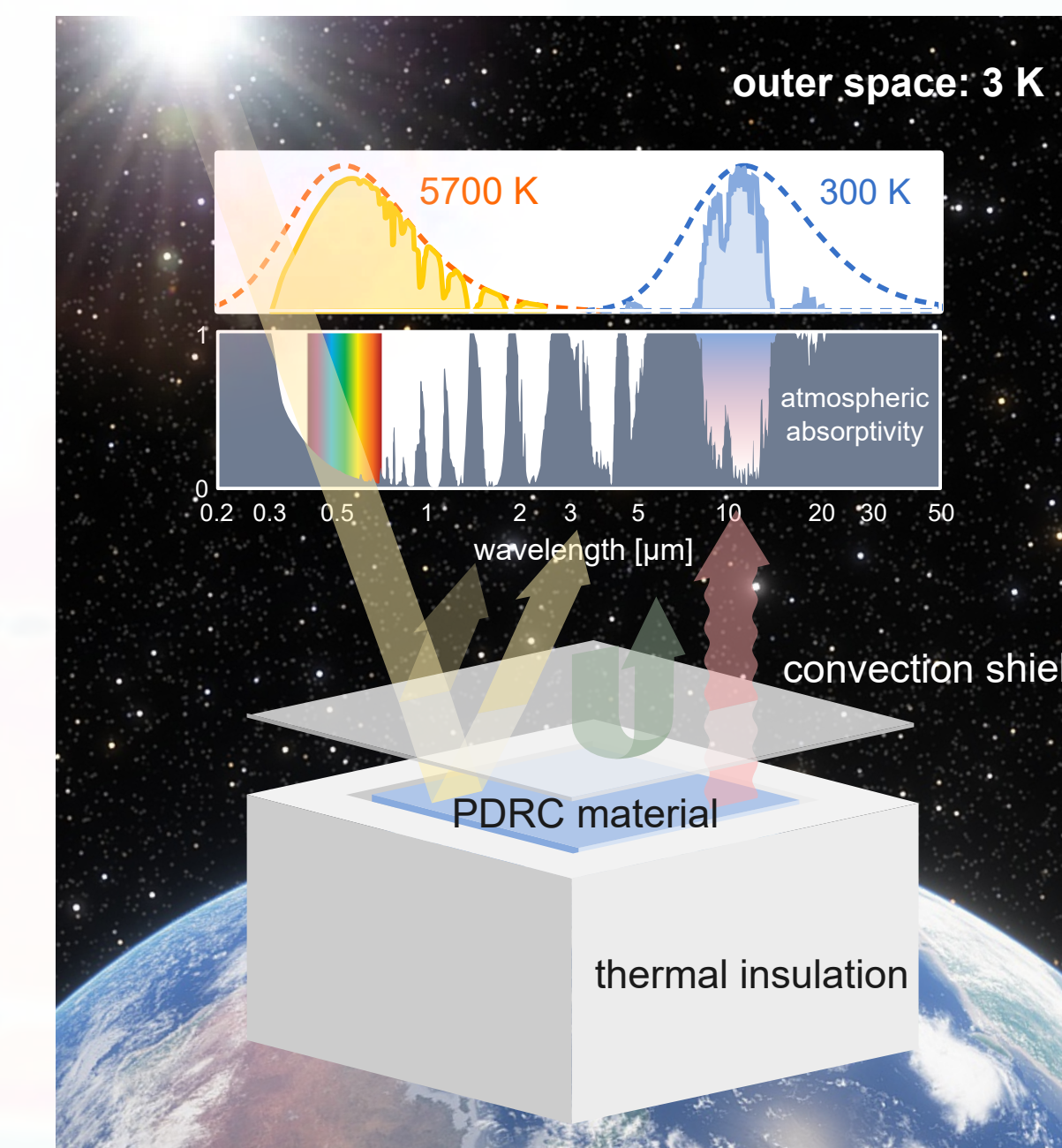
However, there is a general **lack of practices** to assess the **performance of different passive cooling strategies**, which hinders their adoption and leads to suboptimal policies. Current **definitions of passive cooling measures are inadequate** and limited to methods that can limit over-heating rather than providing a net cooling. Additionally, radiative cooling materials require direct sky access, posing an extraordinary challenge to the metrological community to **devise fair testing of these materials under controlled and representative application conditions**.

Sustainable cooling: facts and figures

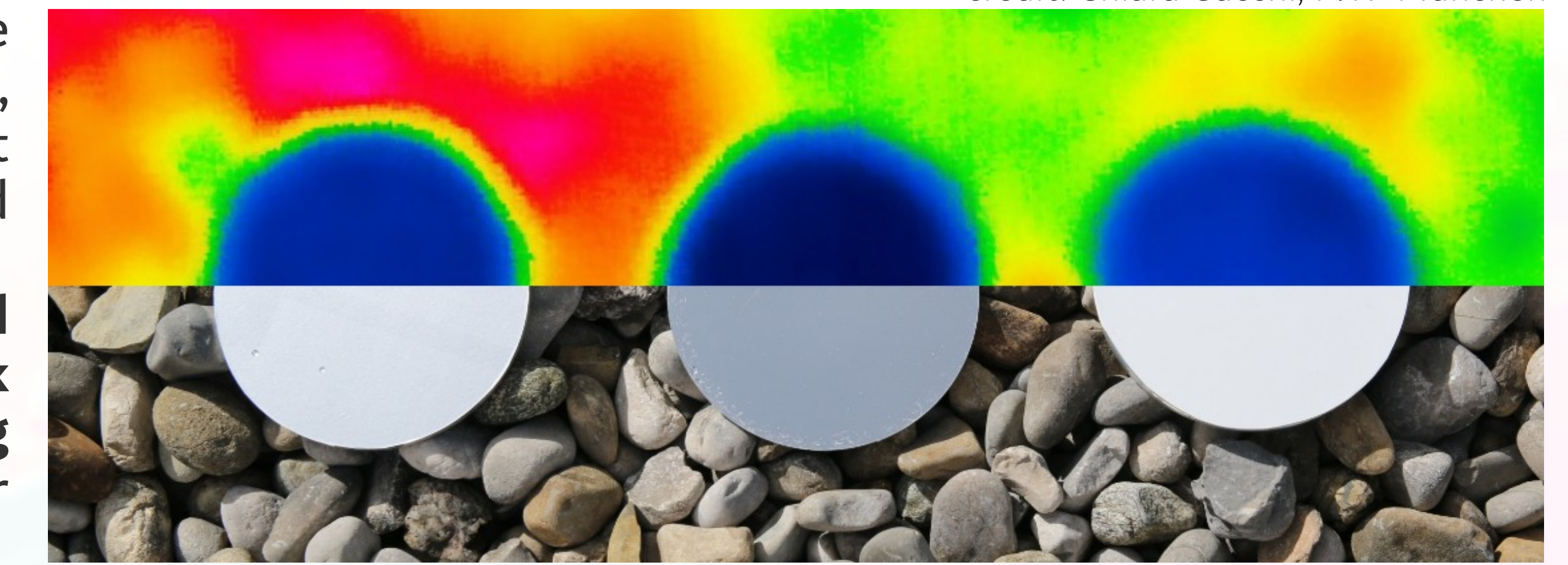
-  **1 in 5 EU citizens** struggle to keep their home adequately cool in summer due to bad urban planning, building standards, or energy poverty (PO of the European Union - Framing Summer Energy Poverty, 2025)
-  Extreme heat is the leading cause of weather-related deaths in the EU, with **72,000** deaths occurred during the 2022 heatwave alone (Copernicus European State of the Climate, 2023)
-  Cooling-related energy needs are growing exponentially since 2000, representing the fastest growing energy consumption (**+5%/year**) (International Energy Agency - Space Cooling tracking 2023)
-  **2.3 billion people** will buy cooling appliances before 2050 at a rate of 10 units per second, requiring **>1.3 TW** of additional generation capacity (Sustainable Cooling for All - Chilling prospects, 2022)
-  Air conditioning drives electricity demand and power outages, leaks refrigerant **F-gases** and exacerbates the **urban heat island** effect (European Environment Agency - Cooling building sustainably, 2022)
-  Access to cooling underpins **all 17 UN Sustainable Development Goals**, and yet remains a critical blind spot in sustainability debates (Future of Cooling - Cooling for sustainable development, 2020)
-  Passive radiative cooling is the only pure passive solution in the taxonomy of cooling technologies, able to remove heat at a rate of **~100 W m⁻²** (PO of the European Union - Cooling technologies overview, 2022)

How does passive daytime radiative cooling work?

Passive radiative cooling has been exploited for millennia, for instance to freeze water under a clear night sky even when air temperature is above 0 °C. This is made possible by a **transparency wavelength range in our atmosphere**, which lets us use outer space as an **infinite heat sink**.



Many materials can be used to achieve passive daytime radiative cooling, ranging from porous foams, to paint layers, electrospun membranes, coated mirrors or dielectric multilayer stacks. This poses the **need to identify and characterise reproducible benchmark materials** for the **comparable testing** of their radiative cooling effect under controlled environmental conditions.

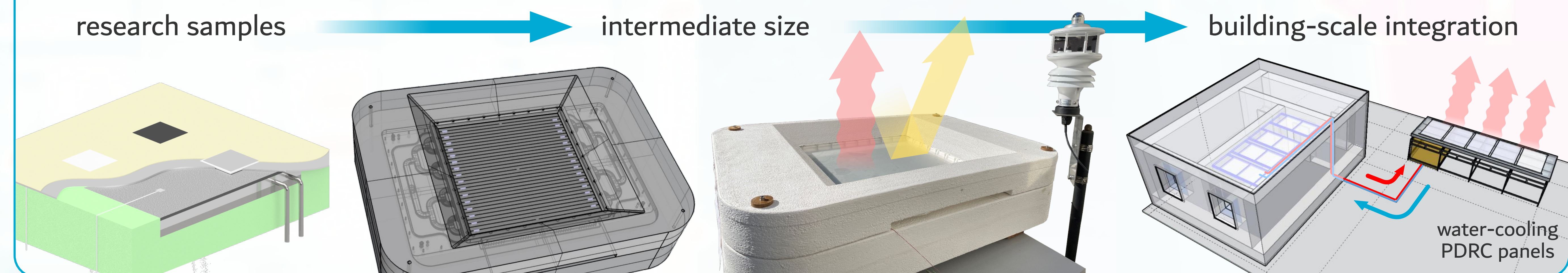


credit: Chiara Cucchi, FIW-München

Define and measure fit-for-purpose figures of merit

Assessing the cooling potential of this new class of materials poses several **metrological challenges**. In the lab, extreme reflectivity and emissivity values must be accurately measured with **directional and spectral resolution** across a wavelength range spanning from the UV to the mid-IR. Cooling performance depends critically also on thermophysical and **heat-transfer properties**, which are particularly difficult to assess for these very **thin coatings**. Yet the most relevant challenge comes from the fact that radiative cooling potential must be tested under **direct sky access** conditions.

This requires the identification of **new figures of merit** and the **design of experimental prototypes** for their assessment, which typically involve the precise measurement of **small temperature and/or heat flux differences in an outdoor environment**, applying controlled (static or dynamic) thermal loads while minimizing the effect of parasitic heat gains from non-radiative contributions. The PaRaMetriC consortium realised several setups for the **testing of radiative cooling materials**, ranging from small research-grade specimens to industrially produced products at full building



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