

Title: Reproducible testing of passive daytime radiative cooling technologies

Abstract

Energy demand for space cooling is rising at an exponential rate since 2000. Passive daytime radiative cooling materials have the potential to address the cooling needs thanks to their ability to dissipate heat through the infrared atmospheric window, with direct application in the building sector, transportation and personal thermal management. However, assessing their refrigeration potential remains challenging due to the inherent outdoor nature of this cooling effect. Coordination among the metrological, research and industrial communities is required in order to develop and validate new approaches for decoupling the characterisation of these materials from variable external conditions, thus enabling the reproducible testing under controlled environment and thermal loads.

Keywords

Passive daytime radiative cooling, Heat transfer, Radiative transfer, Thermal infrared emissivity, Mid-infrared spectral filters, Angular resolved emissivity, Solar reflectance, Test chamber, Heat sink, Solar simulator.

Background to the Metrological Challenges

Accelerating global warming is expected to drive cooling needs to new extremes, which are unsustainable in terms of costs, electricity grid capacity, CO₂ emissions and leakages of refrigerant gases. To mitigate the multiple severe impacts of growing cooling needs, a rapid transition to more efficient and sustainable cooling is needed. Radically new technologies must be urgently identified with the ability to provide net cooling power, with electricity-free and off-grid operation, using sustainable and low-cost solutions. One emerging technology fulfilling these requirements is presented by Passive Daytime Radiative Cooling (PDRC) materials. These are a heterogeneous class of engineered materials exhibiting exceptional reflectivity in the solar wavelength range, combined with pronounced emissivity in the atmospheric transparency window wavelength range (8 - 13 μm). Due to their working principle requiring direct sky access, the cooling performance of PDRC materials is notoriously challenging to assess, prone to biases, and severely affected by the inevitable variability of local testing conditions.

The lack of established testing protocols hinders the evaluation of the cooling potential of different materials currently developed by the scientific community and commercialised by private companies with daytime sub-ambient cooling claims that are difficult to verify independently. Two approaches can be envisioned to harmonise this field. The first one, which was pursued by the recent Metrology Partnership project 21GRD03 PaRaMetriC, is identifying a set of different PDRC materials exhibiting stable PDRC properties. Based on the thorough characterisation of their spectral and thermophysical properties, these materials can be tested in-field alongside with novel PDRC materials to provide a common baseline. While this approach can improve the comparability between different experiments, it does not solve the issue of the different environmental conditions under which each test is inevitably performed. The issue of comparing different products under controlled conditions remains open.

The second approach involves the design and development of a new test chamber tailored to the study of the passive radiative cooling effect to offer full control over the testing conditions, including the instantaneous thermal load applied to the PDRC sample, ambient temperature and humidity, and the distance and visibility from the cold sink. A solar simulator and forced ventilation can also be envisioned to introduce controlled convective losses. Further research is needed to explore this direction and conform the characterisation of

PDRC materials to the standard testing procedures established for other sky-facing technologies that already rely on the use of test chambers to control the testing conditions. Validation is also needed to identify a test chamber configuration that can probe the relevant parameters and provide predictive results for the actual performance of PDRC materials under in-field conditions.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on the traceable measurement and characterisation of passive daytime radiative cooling technologies.

The specific objectives are

1. To define the specifications of a test chamber for the testing of PDRC materials, including recommendations for its constituent sub-components, holders, pressure ranges, heat sink properties and insulation. Specifications should include cycling different view factors and irradiance conditions from the cold sink, ambient temperature, humidity and convection conditions, solar irradiance, heat transfer and sample temperature.
2. To develop calibration procedures for the laboratory characterisation of PDRC materials by using benchmark PDRC materials with known properties inside a test chamber designed to probe their passive radiative cooling potential under controlled conditions. To evaluate the sensitivity of the procedure for PDRC materials of different types (e.g. specular or diffuse reflective, bulk or porous interface, selective or broadband emissivity) and the uncertainty associated with the cooling performance indicators measured in the test chamber apparatus, with a target uncertainty of 10 %.
3. To perform continuous year-round in-field measurements of the cooling performance of the benchmark PDRC materials under various real conditions, with and without convection and/or solar irradiance shielding. To evaluate the net cooling power provided per unit area of emitting surface and maximum temperature drop during different times of the year at the test site locations. To evaluate the application of PDRC materials in thermal energy storage applications, hydronic cooling and thermally activated building systems.
4. To develop a numerical model of the test chamber and validate the characterisation measurements of the benchmark PDRC samples. To correlate the predicted laboratory cooling performance with the actual cooling performance measured in-field under real (instantaneous or time-averaged) atmospheric conditions.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (testing laboratories), standards developing organisations (CEN/TC 89, CEN/WS 107), and end users (e.g. manufacturers of new PDRC products, the European Cool Roof Council, test chamber manufacturers).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented needs, in particular those supporting the European Green Deal. To enhance the impact of the research, the involvement of the appropriate user community such as industry, standardisation and regulatory bodies is strongly recommended, both prior to and during methodology development.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the Metrology Partnership project 21GRD03 and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.8 M€ and has defined an upper limit of 3.5 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the sustainable energy technologies sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Timescale

The project should be of up to 3 years duration.