Reduced Solar Module Temperature

Public Disclosure Report

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Executive Summary

Under bright sunshine, solar panels typically operate 30°C above ambient temperature when rack-mounted in the field and an additional 10-15°C hotter when roof-mounted. Not only does this reduce peak power output by 15-20% below rated performance, but it also accelerates all chemical degradation processes within the panel and shortens its operating life.

The question arises, are there passive cooling techniques that can be built into the module or the mounting structures that enhance cooling, and can this be done cost effectively?

This project targets improved solar panel design to lower the operating temperatures in the field, leading to higher efficiency, and increased energy production. We do this be comparing and testing the benefits of several passive cooling technologies;

- Can we reflect the light from the surface that doesn't contribute to energy production but leads to heating of the module?
- Can we conduct the heat that is generated away from the surface?
- Can we improve material properties to radiate heat efficiently from the surfaces?
- Can we change the structure to improve air flow to remove heat efficiently<

To better understand, we have run simulations to study their effectiveness of different techniques, we have designed and built physical models to demonstrate the practical implications of implementing such technologies, to conduct whole-of-system analysis and to develop practical, cost-effective, and innovative module designs.

The project follows on from a desktop study, co-sponsored by UNSW, the Australian Renewable Energy Agency (ARENA), materials manufacturer 3M Ltd and Australian innovator 5B Pty Ltd.

The aim in this work is to demonstrate module and system design for a target of 5°C temperature reduction. Partnerships with 5B Pty Ltd and 3M Ltd have been maintained and new partnerships have been formed with Australian and International materials and module manufacturers.

In this work, research was focussed in four main areas; conduction of heat, managing air flow and the reflection and radiation of light to reduce temperature effects.

Physical tests were run using wind tunnel testing, outdoor rooftop tests and field tests in operating arrays. With the aim of demonstrating success in passive cooling approaches by reducing operating temperatures by 5°C, resulting in an increase in module efficiency of >2% and an increase in module lifetime by 50%.

Demonstrations, trialling the more advanced outcomes of the study, have shown a cooling effect close to the target 5°C.

Project Overview

Project summary

Operating temperature has a significant effect on both output power and the long-term durability of solar panels. A reduction of operating temperatures by 5°C will increase efficiency by at least 2% and a lifetime increase of 50%.

This project targets real-world demonstrations of passive cooling technologies to panel design. Success will see the delivery of cost-effective and innovative designs to change the way solar panels are manufactured or deployed.

Project scope

The Project had two specific aims:

(1) Demonstrate experimental reduction in operating temperature by 5°C by incorporating the most promising of the targeted passive temperature reduction approaches.

(2) Working with a carefully selected team of local and international industry collaborators to develop and demonstrate practical, cost-effective approaches to modifying commercial module design to capture as much as possible of experimentally demonstrated gains, with minimal change to the way modules are made.

Outcomes and Next Steps

The project brings together established expertise in cell and module design at UNSW, with Australian innovators at 5B Pty Ltd and glass company YCGC Pty Ltd (also known as PCI Green), and a broad range of international materials suppliers (3M and Flat Glass Group) and panel manufacturers (Longi, JA Solar, Canadian Solar and Jinko).

Models and simulations have been developed to assess the different passive cooling options, including experiments with different anti reflection coatings (ARC), glass textures, mechanical fins (Vortex Generators or VGs) and thermally conductive tapes and materials on the back of the panels.

Good progress is being made with clear cooling benefits from both vortex generators and conductive materials. Initial demonstrations, trialling the more advanced outcomes, are already showing a 4.7°C cooling effect, with potential for further improvements with ongoing optimisation.

The project activity will continue, with activity to in the more promising approaches to reduce module operating temperature and will include conduct field testing on full-size modules

Success will see the delivery of cost-effective and innovative module designs to change to the way modules are manufactured or deployed.

Technology Summary

Solar panels/modules heat up through absorption of infrared radiation in the field. The infrared radiation does not contribute to energy generation. In fact, absorption in the infrared detracts from performance by causing the panels to heat up, making them less efficient and shortening the product lifetime.

The module cooling project aims to extend solar module lifespan by reducing operating temperatures, via a combination of four approaches, including;

(i) Reflection to reduce unproductive infrared light absorption,
(ii) Radiation to increase module heat dissipation by radiation,
(iii) Convection to use air flow to enhance cooling and
(iv) Conduction to transfer heat from the cells.

A high-level summary of the models and simulations developed is outlined below.

(i) Anti-Reflection Coatings and Innovative Absorbers to Reduce Infrared Absorption

Antireflection coatings are typically used to maximise the light capture in solar modules - to deliver the greatest power output. But infrared light doesn’t contribute to module power and advanced designs of antireflection coatings can be used to reflect unwanted infrared light.

In this work, different anti-reflective coatings (ARCs) were trialled. The characteristics of these coatings was tested, to develop a layer system with better reflection properties and good durability.

Dense multi-layer ARC (ML-ARC) were produced that exhibited excellent anti-reflection, increased IR rejection and robust abrasion resistance. The results are encouraging, and further modelling suggests optimisation of the number of layers will yield a performance enhancement.

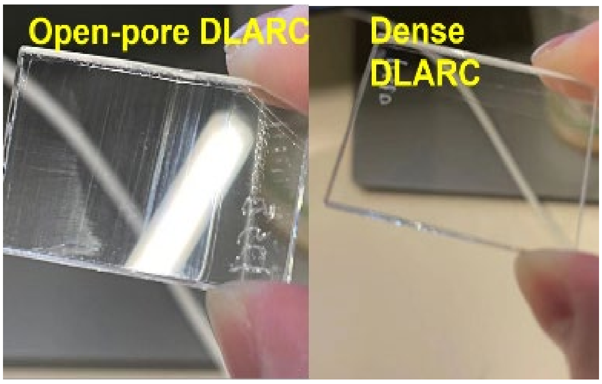

Figure 1. *Photos of (a) open-pore DLARC and (b) dense DLARC after abrasion test.*

The overall assessment of this approach from tests to date, however, is that while the original concept works, in that strong narrowband absorption can modify glass refractive index and thereby influence reflection, the cooling is likely to be insufficient without going to many layers. 8-layer tests are in progress to validate, although additional work will be required to make the approach cost-effective.

The layers developed to date were also tested to demonstrate good lifetimes and abrasion resistance.

(ii) Textured Glass and Backsheet for Enhanced Cooling and Surface Cleaning

Once a surface has heated beyond the ambient temperature it starts to emit that heat by radiation. The emissivity is a measure of how effectively a surface can emit heat – transferring heat to its surroundings. In this activity, we look at increasing the emissivity of module materials so that they can get rid of the absorbed heat more effectively.

Further, texturing of the front glass surface impacts light capture (and thus both performance and heating) as well as influencing how dust and debris collects on the glass surface, optimising texture needs to assess all these factors for best lifetime performance.

Using advanced software, simulations were run to estimate how texturing the surface of the glass can be used to improve the emissivity and what changes we can make to the other module materials such as the back-sheets to help cooling through re-radiation of the heat.

Three types of textured surfaces were investigated – where we balance the optical properties with possible adverse impacts of texture for dust accumulation and self-cleaning.

Field tests showed an optimal performance with glass with a small groove on the front surface, that had a positive impact on light trapping, on cooling and on dust collection, delivering 19.4% efficient minimodules, when a planar minimodule produced only 18.6% under the same build and test conditions.

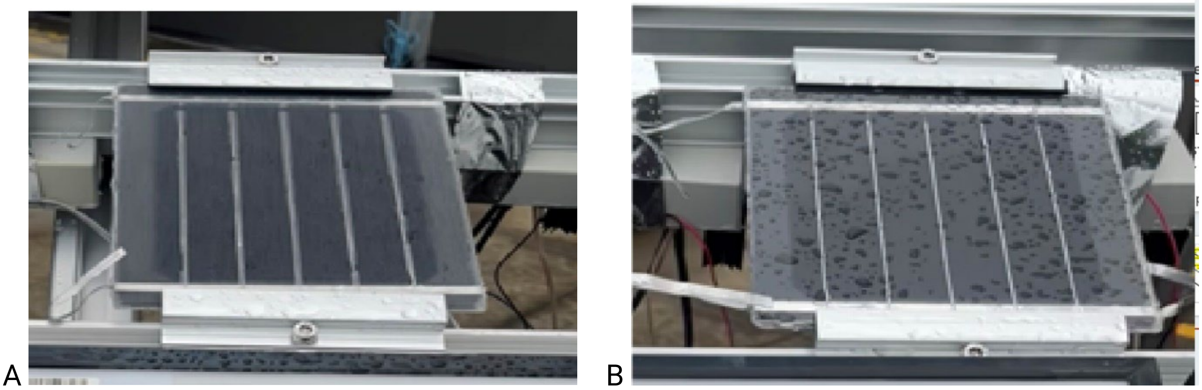

Figure 2. *Minimodules under test with different glass textures; A V-groove and B flat glass*

(iii) Mechanical Vortex Generators and Frame Modifications to Improve Convection

Heat rises from the front surface of solar modules but is trapped on the rear by the panel itself and by the frame. This activity looks at technologies that will improve convection, or air flow, and assist in removing the heat from the rear of the module.

Simulation results reported previously in ARENA project 2019/ARP009 show a strong cooling potential of the vortex generators (VGs) used on the rear module surface. VGs are a small obstruction to wind flow placed on a surface that act to disturb a laminar wind pattern. In the case of solar panels, VGs are intended to increase transfer of heat away from the panel, particularly from the rear surface, where frames tend to cause heat to 'pool' at the back of the module.

Four different promising VG designs were developed to further investigate this area. These designs were mounted on a full-size commercial module and the change in temperature was measured to determine effectiveness. Only the rectangular wing, shown in (a) in the top row of Figure 3 below, had a meaningful cooling effect, proving that it was not just a protrusion on the rear surface that promotes convective heat loss.

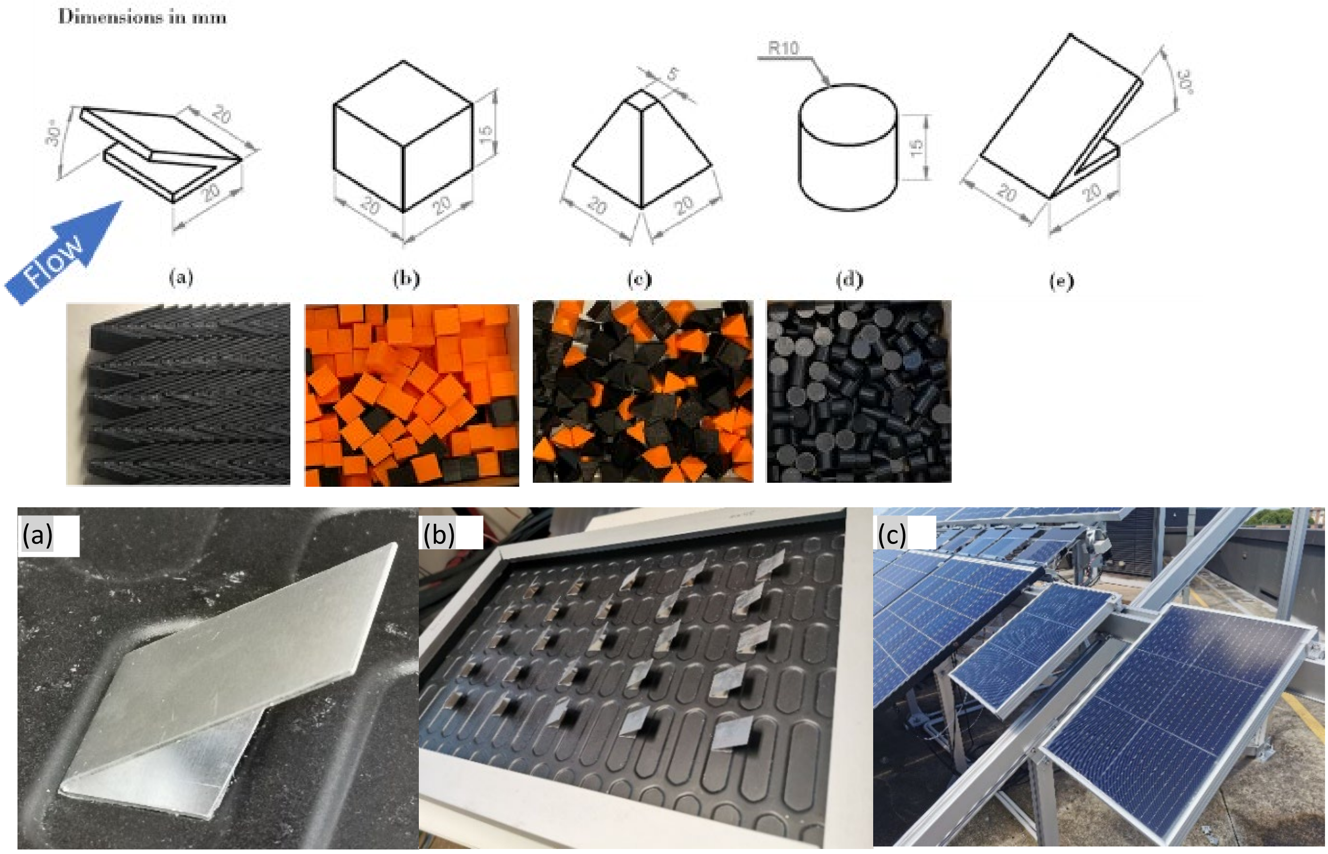

Figure 3. Images of design, build and deployment of passive cooling technologies

Top Row; *The design of the VG with dimension in mm,*

Mid Row: *S photo of the 3-D printed product of each VG design (a) Rectangular Wing, RW; (b) Cube; (c) Truncated Pyramid, TP; (d) Cylinder; (e) Rear-facing Rectangular Wing, RRW*

Bottom Row: *Optimum design as build, (a) close-up of a single VG (b) a test module with both a PCI Green thermally conductive plate and an array of VGs and (C) the modules mounted for out door testing of optimal cooling. One is fully*

At utility scale, modules are assembled in regular and predictable arrays. Different array structures were modelled, including fixed tilt arrays and the innovative MAVERICKs of project partner 5B.

Simulations show that modifying the frame by adding VG's of around 10cm in length could result in 2.2°C of cooling for the module downstream of the VG and a further 1.1°C of cooling for the next module.

Full-Size Module Tests

After modelling and tests on the individual technologies at small scale, an optimised passive cooling approach was determined and built. The six-cell test module relied on both conduction using the PCI Green plate on the back of the module plus convection using vortex generators to maximise cooling.   The vortex generators were designed and produced as part of this project and applied in array across the back of the module.

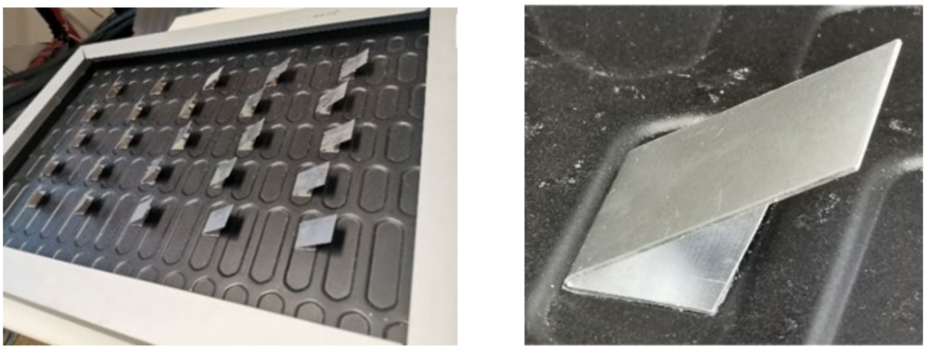

Figure 4. 6-cell test module with both convection cooling using PCI plate and additional VG array to maximise cooling, achieving 4.7°C cooling in field tests.

The convection+conduction module was tested at scale in wind-tunnels at UNSW and on a roof-top test bed at UNSW (shown in Figure 5) below.

Figure 5: Outdoor test arrays at UNSW from a) the front and b) the rear, with one full sized panel covered in vortex generators.

We were successful in lowering the module temperature by 4.7°C in these real-world, field tests.

Further field tests were conducted with industry partner 5B Pty Ltd, with a different design again, using large-scale, frame-mounted vortex generators.   In a controlled test, with a series of modified panels, in an array with standard control panels and in real world tests a cooling effect of 1°C across the modified panels.

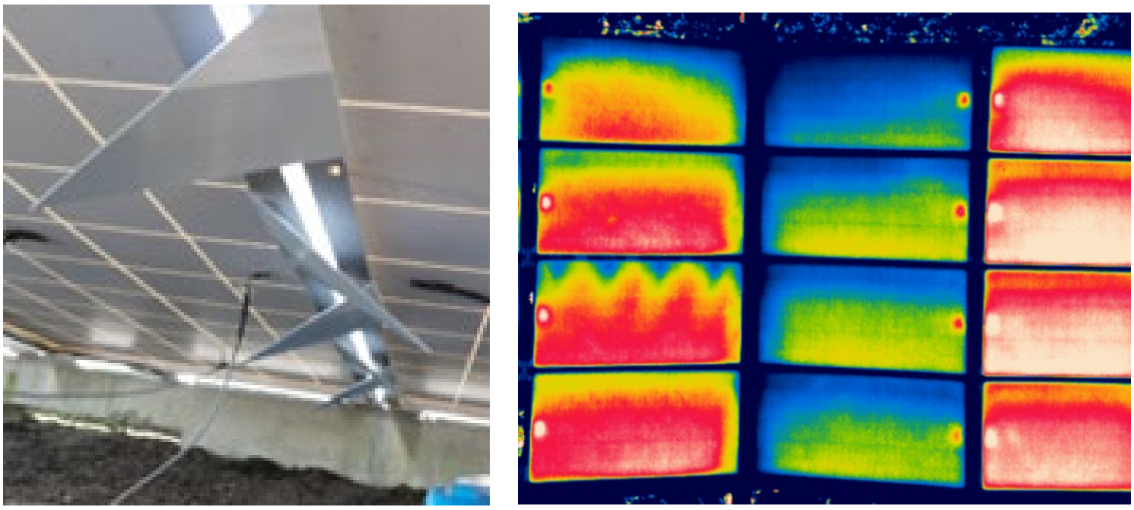

Figure 6: Frame mounted VGs applied to existing array using the 5B system design shown in (a), delivered a 1°C temperature reduction under mild condition, shown by thermal imaging using a drone in (b). The 5B system has rows of panels facing east west, so at any time neighbouring rows are in different thermal environments and comparisons are made between every second row. The first row has been treated with VGs and is compared with the third row.

The project succeeded in demonstrating the possibility of lowering the module temperature by passive cooling technologies, but there is more to do to demonstrate that this can be done cost effectively and with a lifetime that matches the module lifetime. Module lifetime warranties need to be considered as well as a move to bifacial cell technologies.

Conclusions

Under bright sunshine, solar panels typically operate 30°C above ambient temperature when rack-mounted in the field and an additional 10-15°C hotter when roof-mounted. Not only does this reduce peak power output by 15-20% below rated performance, but it also accelerates all chemical degradation processes within the panel and shortens its operating life.

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The team aims to continue studying improvements to passive cooling, extending the work beyond modules to system designs.