Reduced Solar Module Temperature

Project Progress and Lessons Learnt

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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.

This project targets improved solar panel design to lower the operating temperatures in the field, leading to higher efficiency, and increased energy production.

In this work, we aim to compare and test the benefits of several passive cooling technologies.

Not only have simulations been run to study their effectiveness, but physical models have been designed and built to model the practical implications of implementing such technologies.

The project follows on from the UNSW desktop study, co-sponsored by the Australian Renewable Energy Agency (ARENA), materials manufacturer 3M Ltd and Australian Innovator 5B Pty Ltd in order to provide further insight into the optimisation of module and system design for Nominal Module Operating Temperature (NMOT) with a target of >5°C 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

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

Models were built and simulations were run that looked at a whole-of-system analysis to develop practical, cost-effective, and innovative module designs.

The combination of these passive cooling approaches looks to reduce operating temperatures by at least 5°C, resulting in an increased module efficiency by >2% and an increase in module lifetime by 50%.

Initial demonstrations, trialling the more advanced outcomes are already showing a 2°C cooling effect, with simulations showing potential for significant further improvements.

Project Overview

Project summary

Operating temperature has a significant effect on both output power at temperature 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 adding 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 would have two specific aims:

(1) Demonstrate experimental reduction in operating temperature by at least 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 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

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, and a broad range of international materials suppliers and panel manufacturers.

Models and simulations are being developed to assess different passive cooling technologies for module cooling, including experiments with different anti reflection coatings (ARC), glass textures, mechanical fins (Vortex Generators) and thermally conductive tapes on the back of the panels.

Good progress is being made with clear cooling benefits from both vortex generators and conductive tapes. Initial demonstrations, trialling the more advanced outcomes are already showing a 2°C cooling effect, with simulations showing potential for significant further improvements.

The project activity is ongoing, with activity to continue in advancing all approaches to reduce module operating temperature and to 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/module 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 panel to heat up, making it 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 five 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.

A dense double layer ARC (DLARC) was produced that exhibited excellent anti-reflection, increased IR rejection and robust abrasion resistance, an encouraging result and will result in future work on MLARC fabrication.

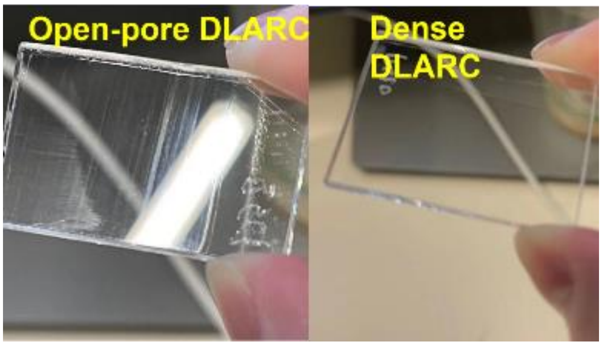

Figure 1. *Photos of (a) open-pore DLARC and (b) dense DLARC after abrasion test.*

A new strategy was also investigated that involve adding elements that created 'resonant absorbers' in the near infrared atmospheric absorption bands that can modify the fundamental optical properties of the glass and so change the reflection properties.

Resonant absorbers were explored both theoretically and experimentally using the element dysprosium (Dy) for its promise in producing strong, localised resonance in soda lime glass.

The overall assessment of this approach from tests to date is that the original concept works, in that strong narrowband absorption can modify glass refractive index and thereby influence reflection. It is, however, unlikely to be a practical approach of reducing NMOT due to difficulties in obtaining the required absorption strength and in controlling side effects associated with unwanted absorption outside the targeted wavelengths.

(ii) Textured Glass and Backsheet Materials to Enhance Emissivity

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.

Using advanced software, simulations are run to estimate how textured glasses 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 are being investigated. We have to balance the optical properties with possible adverse impacts of texture for dust accumulation.

So far, we have found that textured glass is better for cooling than planar glass. It was also found that all backsheet materials presented a low emittance and so an opportunity to improve cooling by increasing the emittance.

Future studies will focus on investigating the most effective backsheet material with high emittance

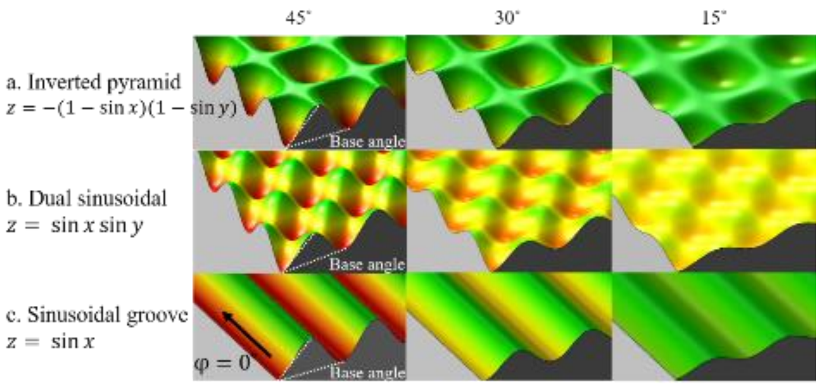

Figure 2. *Three textured surface with three base angles: 45˚, 30˚ and 15˚. Green is higher in elevation; red is lower in elevation*

(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 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. Four different promising YG designs were developed to further investigate this area.

These designs were mounted to a full-size commercial module and the change in temperature was measured to determine effectiveness. Only design (a) the rectangular wing had a meaningful cooling effect, proving that it was not only a protrusion on the rear surface that promotes convective heat loss.

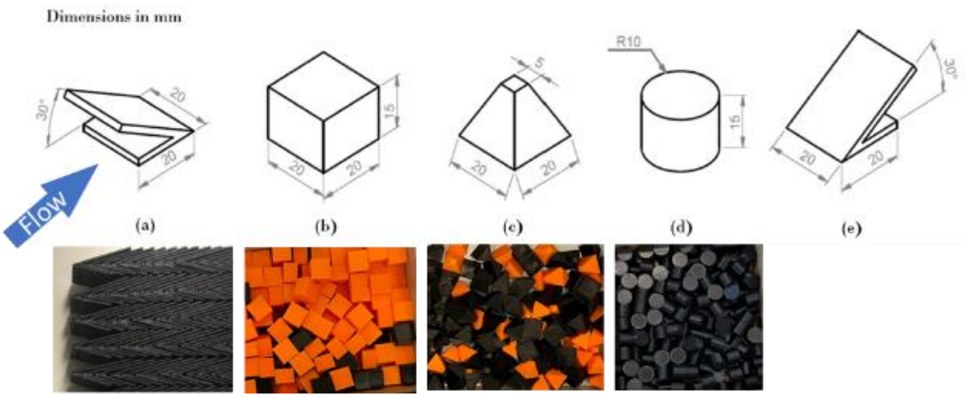

Figure 3. *The design of the VG with dimension in mm, and the photo of the 3-D printed product of each VG design (a) Rectangular Wing, RW; (b) Cube; (c) Truncated Pyramid, TP; (d) Cylinder; (e) Rear-facing Rectangular Wing, RRW*

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.

Several improved frame designs have been considered and simulated in COMSOL and ANSYS FLUENT. The rear of the panel frame normally protrudes around the perimeter creating a recirculation where convective flux suffers. As suggested in a few existing patents, punching an opening on the frame of the PV module is the most obvious way to reduce the size and the impact of the recirculation bubble. The implications to the mechanical strength of the frame when punching holes in the frame was simulated and showed that doing so using elliptical openings will not compromise the rigidity of the frame.

(iv) Heat Conducting Ceramics and Tapes for Enhanced Thermal Conductivity

Heat captured by the module can be conducted away from the cells to cooler areas of the module. The team looks at ways to change the conductivity of the interlayers or adding layers with increased conductivity.

An experimental model was produced that tested the effectiveness of applying heat conducting ceramics and tapes to the rear of the panel.

Conductive tape was created by stacking three different materials – black electrical tape, aluminium foil double sided thermal conductive tape.

An outdoor experiment was run using a full-size commercial PV module in an open circuit condition.

The temperature effects can be seen in thermal images (where red is hot) and in graphs created from a line scan from these images. In the graphs, the red line is the temperature without tape, the blue lines show temperature with the tape.

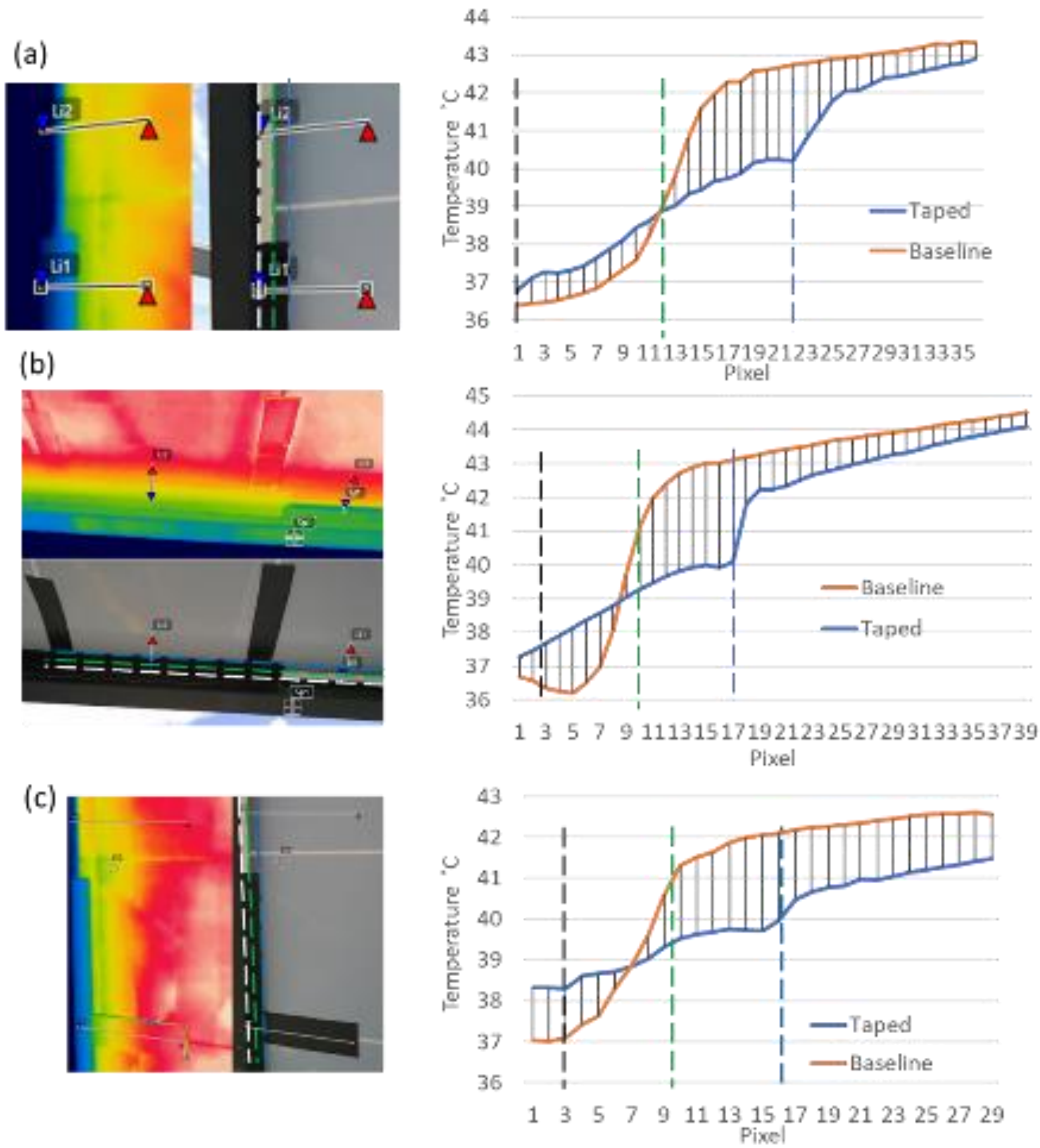

Figure 4. *(a)and (b) with 3cm tape – showing module edge temperature profile modified by the conductive tape; (c) with extended tape – the module edge temperature profile modified by the 3 cm wide tape and extended along the cell gap for around 10cm The black (or white) dash line represents the intersection of the backsheet and the frame, the green dash line shows the edge of the silicon cell and the blue dash line shows the edge of the tape.*

The 'with-tape' results, shown in blue, are lower and flatter – which means the temperature is lower and the change in temperature is smaller. Both these factors provide a positive outcome for module performance and lifetime.

The lower temperature improves cell performance. The more gradual change in temperature reduces stresses in the glass edge.

Different frame materials and colours are expected to have an impact on cooling and will be investigated over the course of the project.

Full-Size Module Tests

We expect each of these cooling technologies to improve module performance individually and that, combined at least 5°C of cooling will be possible. We are working with a range of industry partners including Australian innovators 5B Pty Ltd and glass company YGC Pty Ltd to test the concepts with full scale modules, with full system arrays and in the field.

In the first complete tests, vortex generators (VGs) were produced using 3D printing, from non-conductive materials. These VGs were applied to the rear of full modules and tested in different conditions.

Using these initial VG designs, and with no additional air flow, the test showed 2°C of cooling was achieved with an optimised arrangement. These VGs can be mass produced cheaply through thermoforming or injecting moulding, and a move to more thermally conductive plastic is expected to give us even more effective cooling.

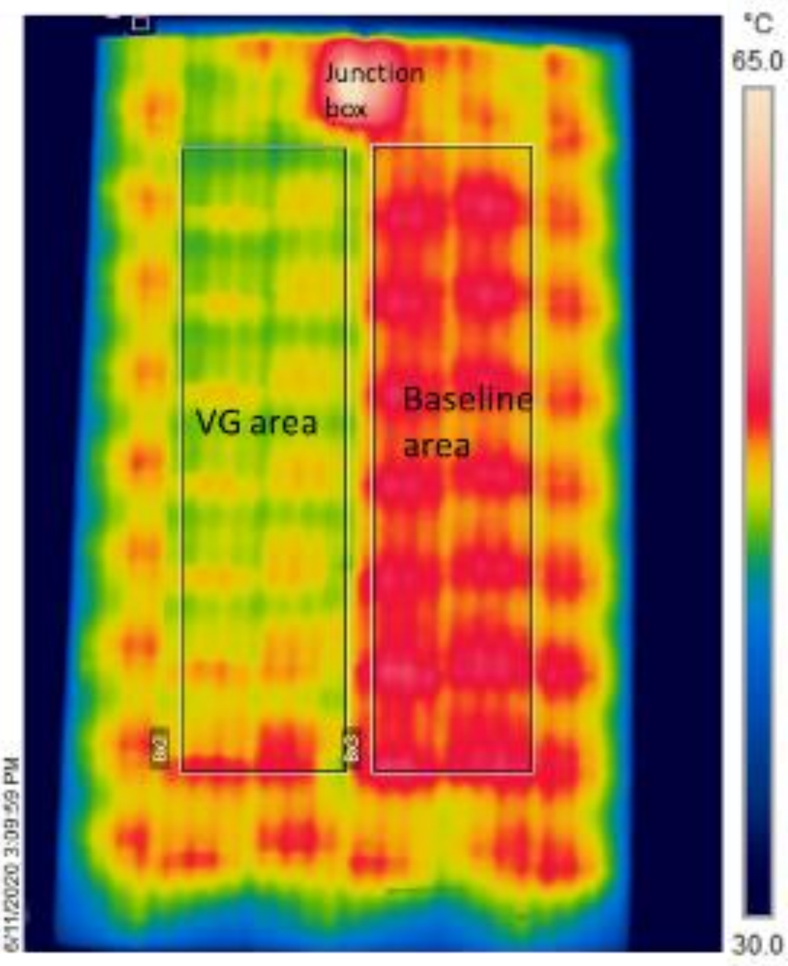

Figure 5: A thermal image of a module showing the benefit of the use of Vortex Generators (VGs) which deliver around 2°C of cooling. The VG area and baseline area are defined.

Lessons Learnt

Lessons Learnt Report:

Project Name: *Reduced Solar Module Temperature*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	NSW

Key learning

- Modelled approaches for passive cooling of modules show good prospects for real-world applications
- Enhanced convective cooling is showing the greatest promise for lowering the module temperature.
- Lessons learnt in enhanced convective cooling can be extended beyond module design to benefit array technologies.

Implications for future projects

Lower module temperatures will improve yield and lifetime from solar power plants.

Knowledge gap

- Manufacturability and cost-effectiveness of the proposed technologies will be the subject of further study in the program.
- The impact of changes to module design on lifetime will need to be reviewed and monitored to assess for unintended consequences. For instance, the addition of new films are being assessed for their durability, the addition of glass texture is being assessed for its impact on dust collection. There may be other interactions that are not yet contemplated.

Next Steps

- Research will continue, in collaboration with industry partners to assess the impact and viability of passive cooling effects on module operating temperature.
- Opportunities exist to work with materials manufacturers, module manufacturers, systems designers and installers, engineering and construction firms as well as plant operators.