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COOL ROOFS
COST BENEFIT ANALYSIS

Volume 14 - Barriers, Implementation Benefits and Drawbacks and Recommendations

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This study is performed to assess barriers, implementation benefits and drawbacks, as well as to develop recommendations for the next revision of the Australian National Construction Code (NCC). Specifically, the purposes of this report are:

- To identify the barriers in the application of cool roofs in Australia and collect recommendations to address these barriers.
- To review previous research concerning the effectiveness of the cool roof application on solar PV efficiency.
- To roughly estimate the installation cost of cool roofs in Australian states and then evaluate the related job creation in order to encourage the development of policies, programs, and markets to deliver cool roofs across Australia.
- To analyse the current regulatory context on the optical-radiative properties of rooftops in Australia in order to offer recommendations that DISER can consider in preparation for the next revision of the National Construction Code, planned for 2025.

The whole study involved the following phases:

Phas H 4 X D Q W L W D W L Y H D Q G T X D O L W D W L Y H D Q D O \ V L V R In the first phase, $ X V W U D O L D Q F six categories of potential barriers are pre-identified for attendees to select from. Additional barriers shared by the stakeholders as well as the proposed recommendations to overcome the barriers, are collected.

Phase 2: Systematic literature review of the literature concerning the effectiveness of the application of the cool roof on PV panels efficiency. During the second phase, selected eligibility criteria for systematic literature review, information sources, literature search and study records, and calculation methodology have been identified, and then the calculation methods for the three most relevant articles are elaborated. Data sources, included Scopus, Web of Science and Google Scholar, were used in this review study. Snowballing was also used on full texts that P H W W K H L Q F O X V L R Q F U L W H U L D 6 W X G \ H O L J L E L O L W \ F U L W H U L D Z H U H OR

- The traditional retrofitting roofs with cool roofs can lead to relevant gains in PV output and additional environmental benefits, including building energy savings and urban heat mitigation.
- Integration of solar PV with cool roofs helps reduce peak electricity demand and PV-cool roofs is able to generate more electricity than PV-green roofs (Green roofs can increase annual PV energy yield by 1.8%, and cool roofs, with higher albedo, can by 3.4% (Cavadini and Cook, 2021)).
- Although PV with a lower tilt angle have a higher performance during summer, and the systems with higher tilt angle have a higher performance during the winter season, the compensation of the cool roof paint can change the general understanding of the tilt angle of PV panels.
- The performance of PV technology in urban context can be improved by : 1) designing panels that can more effectively reject heat that does not turn into electricity (Sailor et al., 2021), 2) high reflective coating IRU 39 SDQHOV ZKLFK PLJKW (Sailor et al., 2021), 3) installing PV panels with distance from the roof to provide air gaps and ventilation (Wang et al., 2006b; Cavadini and Cook, 2021), 4) developing hybrid Photovoltaic Thermal (PVT) collector with various mass flow rates due to their ability to increase outlet temperature, output voltage and output power as well as to decrease panel surface temperature and environmental pollution (Aste et al., 2015; Senthilraja et al., 2020), and 5) developing building-integrated photovoltaics (BIPV) roofing system due to their indirect shading impact and ability to produce electricity, especially with decreasing PV costs (Dehwah and Krarti, 2021).
- The total minimum and maximum potential cost of cool roof installation for all roofs in Australia in 2020 is AUD$6.86b (USD$4.94b) and AUD$89.18b (USD$64.21b), respectively.
- The cost breakdown of building type is 84% residential, 9% commercial, and 7% industrial (as at 2020).
- The estimated minimum annual cost of applying cool roof for new roofs is AUD$168m (USD$121m), and the maximum is AUD$2.19b (USD$1.58b).
- Applying cool roof strategy for total roofs in 2020 could provide between
  - 34,576 to 449,490 direct jobs,
  - 1,008 to 13,105 indirect jobs, and
  - 58,285 to 757,711 induced jobs.
- Annually, the application of cool roofs can provide in average:
  - 5,940 direct jobs,
  - 173 indirect jobs, and
  - 10,013 induced jobs.
- Currently, The NCC sets a maximum solar absorbance of 0.45 for non-residential buildings, without a separate limit for flat and pitched roofs and no limit for residential buildings
- In the current version of the NCC, the provision could be circumvented with a performance solution, missing the climate impacts
- Also, no measurement procedures concerning solar reflectance and thermal emittance are explicitly mentioned in the NCC where the provision on maximum solar absorbance is given
- The following proposals are made in preparation for the consultation before the NCC2025 revision:
  - Proposal 1. Use the Solar Reflectance Index instead of Solar Absorptance.
  - Proposal 2. Add a performance requirement on mitigation of urban overheating in Section J or an entirely new section.
  - Proposal 3. Limits to SRI for all buildings, including residential.
  - Proposal 4. Limits apply to retrofits.

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To overcome these barriers, the initiative that has received the strongest voices is to include heat mitigation considerations into dynamic building performance simulations supporting the verification of National Construction Code (NCC) energy requirements (Section J) for residential (Nationwide House Energy Rating Scheme (NatHERS) or Building Sustainability Index (BASIX) in NSW) or commercial buildings. Specific advocacy was made to consider the benefits of heat resilience components like cool roof materials on micro-climate and energy saving. A low-cost government energy audit process and the auditing of the product claims have also been proposed by multiple stakeholders. Moreover, the attempts to establish the Australian cool roof council, have an agreed National

Figure 4 Technical barriers selected and reported by the cool roof stakeholders.

At this stage, clear guidelines on cool roof standardisation for the Australian market is most urgently needed, see **Table 3**. The focus on further development and commercialisation of cool roof technologies and advancements in cost reduction and efficiency improvement is recommended. Some stakeholders consider an improved paint system that is economical and durable will likely have a much greater direct practical impact than the best technical solution. Stakeholders have also recommended that

- Standardise minimum warranties of no less than 10 years in order to have any commercial viability
- Topcoats to be water-based coatings with a minimum spread rate of 5 m^2 per litre to bring down the cost.

Table 3 Product and technic-based recommendations proposed by the stakeholders to overcome the related barriers and the corresponding votes each recommendation receives

Category	[illegible]	[illegible]
[illegible]		

	Focus on durability. Many of the leading-edge solutions use material that are subject to breakdown with heat and or UV. Any new product must be of similar durability to existing product and no less than 10 years in order to have any commercial viability.	

knowledge about the long-

	Promote aesthetics. This is perhaps a marketing task; however, we should

2. Impact of Cool Roofs on the Performance of PV Systems

2.1 Introduction

Currently, urban areas or metropolitan areas worldwide are significantly warmer than their surrounding rural areas because of the urban heat island (UHI) effect due to the increasing world's population and human activities. UHI is being exacerbated by local and regional climate change, which causes an increase in extreme temperatures, thermal distress, heat stress, and heat-related mortality and morbidity (Santamouris et al., 2017b). Overheating in urban areas is a well-documented phenomenon, occurring in more than 400 cities worldwide (Santamouris, 2019). Urban overheating is largely caused by synoptic weather conditions, thermal properties of the materials (absorbing solar radiations or opaque surfaces that release heat), limited evaporative surfaces, lack of vegetation,

of selected papers either focused exclusively on cool roof technology or PV systems, and only 10 of them conducted an integration of two systems.

Figure 9 Number of papers published with respect to their employed methodology

Table 6 shows the characteristics (Article title, Country/climate type, Source title, Author/s, Year of publication, Research aim, Methods and findings) of the more relevant articles that were used in this review study. The articles ZHUH GLYLGHG LQWR ³GLUHFWO\ UHOHYDQW´ DQG ³LQGLUHFWO\ UHOHY for the most relevant articles were explained.

[illegible] 6 characteristics of the more relevant articles that were used in this review study (**[illegible]**: blue sections, **[illegible]**: green sections). The articles were ordered chronologically.

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1					

No	[illegible]	[illegible]	[illegible]	Fi[illegible]	[illegible]
3	Zurich, Switzerland	• To develop a calculation method that takes into account the characteristics of roof surfaces when simulating PV panel energy yield. • comprehend how four roofing configurations (black membrane, white membrane, rock ballasted and vegetated) affect PV panel yield	Theoretical Experimental • The modified System Advisor Model (SAM) • Rooftop energy balance model to estimate the roof surface temperature (this stage provides input to the modified SAM version)	• The adapted SAM model contribute planners and stakeholders to compare the benefits of different rooftop configurations • The thickness and the thermal conductivity of the roof have a huge impact on surface temperature. • A sustainable roofing configuration could increase the annual energy yield of PV panels in Zurich by 3.4% for a cool roof, on average. It shows that for every 0.1 increment of roof albedo, the annual energy yield of PV increases by 0.71%. • For green and cool roofs, respectively, surplus electricity could represent 15% and 28% of the annual household electricity consumption. • Changing to cool roofs would produce, on average, 60 GWh more per year.	(Cavadini and Cook, 2021)
4	Texas, United States	• To analyse and present the impacts of cool roof coating on roof-mounted photovoltaic solar modules at texas green power microgrid	Theoretical Experimental • Modelling thermal analysis by installing the THERMAX • Installing Tigo power optimiser at each module • Comparing the percentage of power generation by cool/hot module along with load and battery performances • Comparing ENERGY STAR® certified cool roof by changing cool roof characteristics	• Sol-air temperature measurement showed an increase in system H I I L F L H Q F \ R I Z K H Q F R R O L Q J O R D G Z • A 14.9% increase in overall efficiency • An additional 10.41% of solar power and an extra 9.37% of current production when comparing cool and hot energy sources	(Rahmani et al., 2021)

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	-	ƒ To explain the role of urban surfaces in developing climate resilient and sustainable cities ƒ To propose a catalogue of solutions for the urban surface use. The catalogue offers the main surface uses suitable for the built environment. It also discusses the potential conflicts and synergies among them in the view of a multiple and integrated utilisation of urban surfaces.	Theoretical		

No	Lia Chan

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	Australia	*f*			

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	Sharjah, UAE	ƒ To investigate the impact of cool roof			

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	-	*f* To review studies about roofing methods for flat roofs. Ten roofing methods are			

No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	Greece	ƒ To investigate the PV roof effect annually on E X L O G L Q J ¶ V H demand (reducing the cooling and heating building loads) during different seasons	Theoretical Experimental	ƒ Based on the simulation results, seasonal heating loads increase by 6.7% and cooling loads decrease by 17.8% in the top floor under typical energy management considerations. The BAPV roof external flow is dominated by complex and time-dependent conditions and strongly influenced by the temperature difference between the surface and the fluid. ƒ the top floor of the building's energy performance improves due to a decrease in total weighted heating and cooling load demands by 3.2% on an annual basis. ƒ In order to achieve efficient design and enhanced net zero energy operations, the effect of roof added PV panels needs to be taken into consideration for seasonal strategies.	(Kapsalis and Karamanis, 2015)
22	Milan, Italy	ƒ To develop a mathematical model for estimating the electrical and thermal production of an innovative glazed PVT component with water as the heat transfer fluid.	Theoretical Experimental	ƒ As part of the proposed model, various terms affecting the performance of hybrid collectors are taken into account, such as the spectral efficiency, the angle of incidence of solar radiation on the surface, the temperature loss and the thermal inertia of the collector. ƒ It has been shown that the numerical model has provided accurate simulations of the daily thermal and electrical performances on days with different weather conditions. ƒ Regarding primary energy, PVT technology offers higher overall efficiency than simple PV modules.	(Aste et al., 2015)
23	Greece	ƒ To examine the shading and cooling effects of roof-mounted photovoltaics (PV)	Theoretical Experimental ƒ TRNSYS simulation	ƒ PV panels have a significant effect on roof surface temperature between shaded and exposed portions of the roof during the summer. ƒ As well as generating electricity, the rooftop PV system can passively reduce the daily rooftop cooling energy and peak load during the hot summer days.	(Kapsalis et al., 2014)
24	-	ƒ To review previous studies on water flat plate PV-thermal collectors	Theoretical	ƒ An up-to-date overview of the technology is presented here, with a special focus on recent technological advancements and on the future of the field.	(Aste et al., 2014)

2.3 Ctlh

This section elaborates on calculation methods for the three most relevant articles:

2.3.1 3*UHHQ DQG FRRO URRI FKRLFHV LQWHJUDWHG LQWR URRIWRS V Ciaelcko (2021)

Currently, there are different solar energy models such as System Advisor Model[1] (Blair et al., 2018), PVlib (Holmgren et al., 2015), and PVSYST (Mermoud and Lejeune, 2010) that use energy and mass equations to simulate a range of PV configurations and climatic systems. These models, however, do not take the

- 'HVLJQLQJ DQG IDEULFDWLQJ D WDLORUHG SDQHO¶V UDFN that was LQ WK coated with special reflective paint (cool coating) and combined with the PV panels support rack).
- Measuring increased solar radiation onto the PV surface by sensors and storing digitally with a data logger and workstation

Seven parameters were applied to compare the readings, including Irradiance difference in W/m2, Power difference in %, Energy production difference assuming 16% efficiency, Energy in WH without cool painted carpet (or with black carpet), Energy in WH with cool painted carpet, and Energy difference in WH.

Overall, these experiments confirmed that:

- There is a possible impact of 5 ±10% improvement with the cool roof applications.
- Mainly climatology, orientation, latitude, azimuth angles, tilt angle, and in a particular geographical region and usage over a period of time, affect the performance of PV systems (Yakup, Mohd Azmi bin Hj Mohd and Malik, 2001; Said and Mehmood, 2017). As previous studies showed, the systems with higher tilt angles have a higher performance during the winter season, and the systems with lower tilt angles have a higher performance during summer (Yakup, Mohd Azmi bin Hj Mohd and Malik, 2001; Babatunde et al., 2018).
- The higher the tilt angle, the higher the irradiance levels. A PV panel with a cool coating generate more power at angle 45, largely due to the greater amount of reflection and solar radiation generated by the cool coating, part LFXODUO\ DW WKH H[SHULPHQW¶V WLPHIUDPH
- ³&RRO &DUSHW´ FDVH SHUIRUP PRUH HIIHFWLYHO\ DW DQG G between the average of power difference. The average power difference at angle 45 is 2.9%, and at angle 35 it is 4.0%.

2.3.3 ³&RRO URRI FRDWLQJ-tilting LPSDFW RQ URRI SRZHU PLFURJULG´ E\ 5DKPDQL HW DO (2021)

Rahmani et al. (2021) did comprehensive thermal analyses for residential buildings in this study, focusing on the analysis of the cool roof-mounted solar photovoltaic system. They apply 186 solar photovoltaic 330-W Arthe

2.4

2.4.1 PV

As discussed before, cool roof technology reduces urban air temperatures by decreasing the quantity of heat transferred from roofs to the urban environment (Zinzi and Fasano, 2009; Zinzi and Agnoli, 2012). Cool roof application also improves indoor thermal comfort, and it decreases energy bills by decreasing the usage of mechanical air conditioning systems (Pisello et al., 2013). Various recent studies show that cool roof technology is one of the most efficient rooftop mitigation strategies in decreasing air temperature and energy consumption in the urban context (Akbari et al., 2005; Santamouris et al., 2011; Santamouris et al., 2021; 2021). Extrapolating and analysing previous studies show that replacing dark roofs with cool roofs can save

G H V H U (Broadbent et al., 2019). While some studies refer to Increasing albedo by 0.05 as a way to diminish the negative impact of urban deployment of low-e solar PV (Taha, 2013) V R P H R W K H U V V D L G X V L Q J D O E H G R´ W R D Q D O \ V H W K H F R U U H O D W L R Q R I 3 9 P R G X O H V, and urban air temperature is only a simplification which can lead to erroneous predictions (Sailor et al., 2021). These conflicting results are because some studies assume PV panels are thermally massive surfaces with an effective albedo which is an incorrect assumption (Sailor et al., 2021) experimental study conducted in a Mediterranean climate compared the conventional roof with PV panels and concluded that an integrated roof could increase heating loads by 6.7% in winter and cooling loads by 17.8% in summer (Kapsalis and Karamanis, 2015). However, the produced energy depends on multiple environmental factors such as day to day variation due to temperature fluctuation, clouds, precipitation events, shading and soiling. Dominguez et al. (2011) also conducted measurements of the thermal conditions through a roof profile on a building partially covered by PV panels in California. Thermal infrared images taken on a clear April day showed the PV arrays to be 2.5 °C cooler than the exposed roof during the day. The roof heat flux under the PV array also reduced significantly during the day. Their study showed that PV-covered roofs reduce annual cooling load by 5.9 kWh/m^2 or 38%.

As discussed before, reducing PV cell temperatures can improve PV efficiency. In 2010, Yozwiak and Loxsom (2010) developed a low-cost method to passively cool roof-mounted photovoltaics to improve electricity production. Their original system consisted of an aluminium plate in thermal contact with the module back and a fin extension exposed to the open air. They found that both fin systems, which differed by the length of the exposed fin, provided an average 0.12°C cooling effect when the temperature gradient between the modules and the ambient was greater than 1°C. The study proved that the concept of a plate with an exposed fin could effectively cool a roof-mounted photovoltaic module. Similarly, another study stated that the effect of PV ventilated roofs on cooling load reduction is the same as cool roofs with a reflectance of 0.65 (Wang et al., 2006b). However, the impact of installing PV on top of a cool roof system on heating energy has not been fully investigated in the literature (Dehwah and Krarti, 2021).

Shading of the building from solar radiation also impacts building energy demand. The roof shaded by solar panels can increase domestic heating needs by 3% in the winter (Masson et al., 2014); however, it results in a 12% reduction in the energy needed for air conditioning during summer. It also reduces the UHI effect and reduces surrounding temperatures by 0.2 °C on summer days and up to 0.3 °C at night.

Summertime heat flux through the roof deck can also be reduced after installing PV panels on roofs and applying cool roof strategies. PV has resulted in a substantial heat flux reduction, about 60 ±63%, and cool roofs resulted in 33% heat gain reduction requiring the replacement of black roofs with cool roofs or PV-cool roofs (Park et al., 2019). In terms of an integrated roof, the preliminary simulation results indicate that for a reference conventional roof (U value = 2 kJ/h m^2 K, gre \ ! WKH %,39 FDQ UHGXFH WKH K
ZKHUHDV D FRRO URRI ZLWK ! FDQ UHGXFH WKH KHDW IOX[E\ DEF (Kapsalis et al., 2014).

However, the size of both energy savings and heat reduction depends on factors such as the albedo of roof surfaces being shaded, climatology conditions, the level of building insulation, and other building construction and operation characteristics. Therefore, the impact of PV on building energy demand depends on many factors and then generalising the impacts is difficult (Sailor et al., 2021).

2.4.4 PV

There are several factors affecting the efficiency of PV technology, such as climatology conditions, roof design, panel tilt, panel slope, Solar PV type, distance from the roof, cell temperature, the temperature on the back of the panel, solar panel shading, long-wave radiation on the back of the panel, power-efficient and installation types such as land-based solar farms or floating PV panels. In addition, despite the fact that most currently installed and available PV technologies have an electrical efficiency rating of between 15% and 20%, the actual working efficiency may differ significantly from these values, especially during hot summer months (Sailor et al., 2021). Further, the UHI effect, air pollution, partial shading due to scarcity of open space in urban areas and accumulation of contaminants on the PV surface (soiling) may result in further loss of PV efficiency (Sailor et al., 2021).

Some research showed that PV panels perform better during colder months in some climate zone (e.g., Sailor et al., 2021, Chumpolrat et al., 2014, Oh et al., 2010). Research conducted in an experimental study in Thailand found that PV power output peaks when the ambient temperature is lower than 35 °C on a monthly basis (Chumpolrat et al., 2014). Another study from Arizona showed that the power generation of PV panels was reduced by 30% due to high PV cell temperatures (around 90°C) (Oh et al., 2010).

Sailor et al. (2021) suggested multiple approaches to reduce PV cell temperatures, such as: 1) Cool the underside of the PV panel by circulating coolant, 2) use phase change materials (Hasan et al., 2016; Kibria et al., 2016; Kant et al., 2020), 3) combination of rooftop PV systems with green roofs. While these approaches can add capital cost to the system and increase module construction costs, they are able to decrease cell temperature and increase PV efficiency. Another study has shown that PCM's use can reduce cell peak operating temperature by nearly 7 °C (Hasan et al., 2016). Using silicon heterojunction technology was also mentioned as a possible material to achieve efficiencies above 20% in high-temperature environments. However, these materials could act differently in different climate zone (Descoeudres et al., 2015).

The optimum performance of a PV panel also depends on the amount of incident solar radiation on it. So, a panel needs to be inclined at such an angle that maximum sunrays intercept its top surface vertically. So, Tilt angle impacts the performance, efficiency and electrical parameters of a PV module because PV panels'
23[(e)5(specalld)5(y)84(in 209(hot 274(climate)5(n 209Reys)6e(arch -19(sho)7(sy)-5( )21(t)9((at)21(ca)-2irsi)4(g)49
performance depends on the amount of received solar radiation. Every 5° increment in module tilt can decrease indoor power output by 2.09 W and outdoor power output by 3.45 W (Mamun et al., 2021). So, the higher tilt angle, the higher the irradiance levels (Altan et al., 2019). However, the integration of solar PV with cool roofs application can act differently in winter and summer. PV panels applied on the cool roof generate more power at angle 45, mainly due to the greater amount of reflection and solar radiation generated by the cool coating paint. In addition, PV with a lower tilt angle have a higher performance during summer, and the systems with a higher tilt angle have a higher performance n the winter seaion, Thn,( )-6[(the)853(co)-3(ol)897(ro)-2(o')-

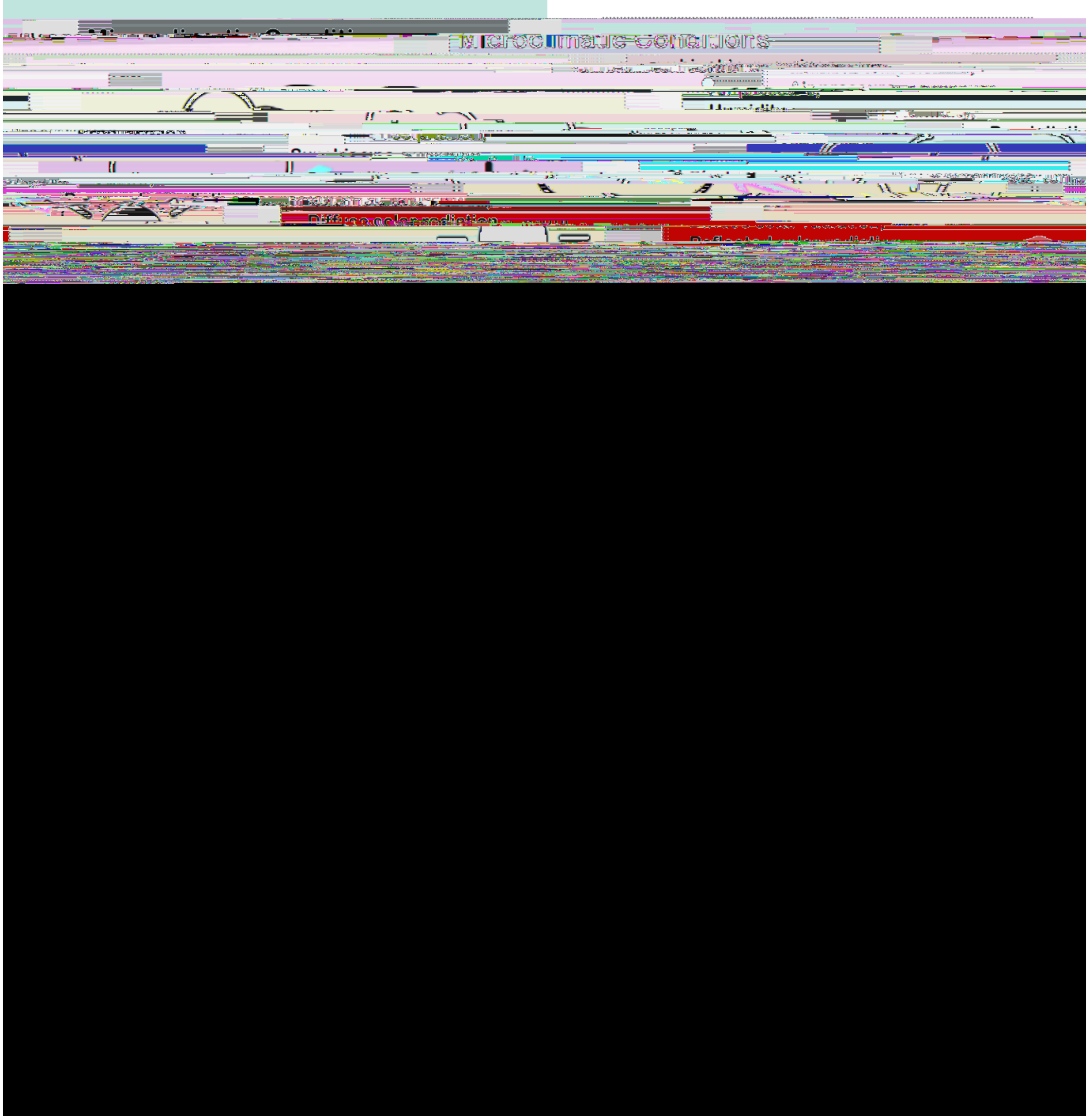

Fig 12 Criteria for evaluating the effectiveness of solar PV applications integrated with cool roofs application

,Q WKH SUHVHQW UHSRUW WKH HIIHFW RI FRRO URRIV RQ 39 VRODU S reviewing previous studies. Some studies mentioned roof albedo as the most important factor impacting the efficiency of both cool roofs and PV panels. The inferences of the study are summarised in the following way:

- For every increase in roof albedo by 0.1:
  - The annual energy yield of PV increases by 0.71%-1.36%.
  - Cool roof performance increases by 14%.
  - Roof surface temperature decreases by 3.1-5.2 °C. A decrease by 1 °C in the roof surface temperature increases PV system efficiency by 0.2-0.9%.

However, these correlations depend greatly on several factors, including panel efficiency assumptions, the albedo of the reference scenario, location of PV-cool roofs, type of building, and the scale of our atmospheric model (mesoscale or microscale).

Overall, the following conclusions have been drawn:

1. The traditional retrofitting roofs with cool roofs can lead to relevant gains in PV output and additional

4. The majority of studies have either focused exclusively on the impacts of cool roof technology or PV

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3. Co lfiMtPa

3.1 Itd

Cool roofs are currently emerging as one of the most important strategies to lower the temperature of buildings, improve indoor comfort and safety, reduce energy bills

3.3 Alb [illegible] 2015 to 2020

According to the estimated data from NEXIS, around 67 km^2 of new roofs were installed from 2015 to 2016 (see [illegible] **8**). The roof area installation was increased by 310 km^2 from 2016 to 2020, with around 77.5 km^2 new roof installation each year (see [illegible] **9**). According to Volume 1 (International Progress, Technology, Market, and Legislative Frame) on average, each stakeholder installed 12,909 m^2 cool roofs in Australia in 2021.

[illegible] 8 New roof installation, 2015-2016

[illegible]	[illegible] (m^2)	[illegible] (m^2)	C[illegible] (m^2)	[illegible] (m^2)	[illegible] (km^2)
NSW	14,548,087	4,405,844	1,661,673	20,615,604	21
VIC	3,902,283	4,763,536	13,969,306	22,635,125	23
	6,291,561	2,771,664	3,143,809	12,207,034	12
SA	2,030,255	259,805	1,098,165	3,388,224	3
WA	8,772,601	-639,555	-2,539,012	5,594,035	6
TAS	407,143	165,112	66,766	639,021	1

11 Minimum and maximum cost for the total roof in 2020 (USD[6])

Min

(USD)

12

14 Direct job creation in 2020 (for total roof area)

3.6 Cb [illegible]

- The total minimum and maximum potential cost of cool roof installation for **[illegible]** in Australia in 2020 is AUD$6.9b (USD$4.9b) and AUD$89.2b (USD$64.2b), respectively.
- The cost breakdown of building types is 84% residential, 9% commercial, and 7% industrial (as at 2020).
- The estimated minimum annual cost of applying cool roofs for **[illegible]** is AUD$168m (USD$121m), and the maximum is AUD$2.2b (USD$1.6b).
- Applying cool roof strategy for total roofs in 2020 could provide between
  - 34,576 to 449,490 direct jobs,
  - 1,008 to 13,105 indirect jobs, and
  - 58,285 to 757,711 induced jobs.
- Annually, the application of cool roofs can provide on average:
  - 5,940 direct jobs,
  - 173 indirect jobs, and
  - 10,013 induced jobs.

4. P[illegible] 2025 [illegible] B[illegible] C[illegible] A[illegible]

4.1 I[illegible]

The scope of this report is to analyse the current regulatory context on the optical-radiative properties of rooftops in Australia. The objective is to offer recommendations that DISER can consider in preparation for the next revision of the National Construction Code, planned for 2025. The points defined for Part 3b of the research project include the development of recommendations on:

- x Proposals on the changes needed to be made to the existing requirements in the National Construction Code, such as alternatives to the current Solar Absorptance measure (e.g., Solar Reflectance Index) and what industry education will be needed for this.
- x Recommendations for steps needed to advance usage in Australia. E.g.:
  - o Standards
  - o Code stringency
  - o Guidance, knowledge sharing or demonstrations
  - o Incentives
  - o Premiums for these new products compared to other roofing products
- x Proposals on the desired thresholds for sloped and flat roofs for the different climate zones and buildings regarding solar reflectance, emissivity, 3-year aged values, lifespan, and mould and condensation reduction.
- x Proposals of the structure of a testing and accreditation infrastructure in Australia, including the assessment of aged values of solar reflectance and thermal emittance.

In this section, a proposal is developed on the proper standards for cool roofs in different types of buildings and climate zones, the appropriate path to be followed to create a standard for roofs, the necessary dissemination and training activities, the required certification and accreditation activities, an efficient demonstration activity, the creation of an Australian cool roof Council, potential incentives to be offered, ways to enhance industrial activity in Australia, and proposals to attract International Industry.

4.2 A[illegible]

Currently, solar reflective roofs are included in the Building Code of Australia (National Construction Code, Vol 1 & 2) only as a Deemed to Satisfy provision, for non-residential buildings from class 3 and 5 to 9, in climate zones

The Deemed-to-Satisfy Provisions of this Part apply to building elements forming the envelope of a Class 2 to 9 building other than J1.2(e), J1.3, J1.4, J1.5 and J1.6(a) which do not apply to a Class 2 sole-occupancy unit or a Class 4 part of a building.

Also, there is no prescription on the maximum solar absorbance of Class 1 buildings. Thus, for non-residential buildings, the maximum solar absorbance is set to 0.45 for rooftops of buildings in Australian climate zones from 1 to 7 (i.e., all excluding Alpine), as defined in NCC Vol 1 J1.3(b) **(Fig 13)**. In some situations, the prescription is modified in South Australia **(Fig 14)**, indicating a maximum solar absorbance of 0.40 **(Fig 14**

- Opting for a Performance Solution could circumvent the prescription of maximum solar absorbance. A building with a dark solar absorptive roof could still comply with the NCC with one of the defined verification methods, thus demonstrating an energy consumption below the defined thresholds.
- There is no prescription on a threshold for the thermal emittance.
- There is no differentiation between low sloped and pitched roofs, for which separate thresholds are normally provided in similar building codes such as the California Title 24. This differentiation is indirectly given in part only in the South Australia annexe (SA J1.3).
- There is no indication of a standard test method or reference spectrum against which the solar absorbance should be computed (ASTM E903 is referenced only in schedule 4).
- There is no indication of requirements on the performance over time of roofing products, as ageing ± namely the combined action of weathering, soiling, biological growth, mechanical and chemical stress ± can cause significant losses in solar reflectance while not significantly affecting thermal emittance (Paolini et al., 2020; Sleiman et al., 2014).

4.3 P[illegible] NCC2025 [illegible]

The first set of proposals to be considered for the consultation process leading to the NCC2025 revision address the points not currently covered by the 2019 and 2022 editions of the Building Code of Australia. The proposals are prioritised as follows:

Proposal 1 . Use the Solar Reflectance Index instead of Solar Absorptance . Currently, there is no threshold for the thermal emittance, which should be addressed. It would be advisable to use the solar reflectance index (SRI) as a threshold instead of the solar absorbance. The solar reflectance index is a parameter that combines the solar reflectance (SR) and thermal emittance (TE), and it is computed according to ASTM E1980(ASTM International, 2011). For a white roof having SR = 0.80 and TE = 0.90 the SRI is set to 100, while SRI = 0 for a black roof with SR = 0.05 and TE = 0.90. The SRI for any combination of SR and TE is then linearly interpolated considering the surface temperature it would have in standard summer conditions, scaled between the comparison white (SR = 0.80, TE = 0.90) and comparison black roof (SR = 0.05, TE = 0.90).

The advantage is to have a single parameter defining the performance. Also, this way, it is possible to define DQ ³HTXLYDOHQW 65,´ IRU JUHHQ URRILQJ ZLWK ORZ VRODU UHIOHF evapotranspirative cooling, thus mitigating urban overheating. Alternatively, it is possible to set thresholds separately for SR and TE, which would introduce less flexibility for non-conventional products.

While for opaque surfaces, the solar absorbance (SA) is simply the complement to 1 of the solar reflectance (i.e., SA = 1 ±SR), all measurement methods report solar reflectance or albedo because it is the direct output of measurements. This alignment might simplify and harmonise information management and avoid miscommunication and comparisons with international building codes.

Proposal 2 . Add a performance requirement on mitigation of urban overheating in Section J or an entirely new section . The prescriptions on the SRI (or minimum solar reflectance and thermal emittance, or

Solar Reflectance Index. It is covered only by an ASTM standard, and there are no equivalents in AS, ISO, or EN.

- ASTM E “Standard Practice for Calculating Solar -Sloped Reflect Opaque Surfaces (ASTM International, 2011)

Fig 15 Spectrophotometer with an integrating sphere, with a detail of the photomultiplier and PMT detector (in this case) at the bottom of the sphere and then the measurement beam at the reflectance port.

There is only one standard method covered by ASTM for measurements with a portable reflectometer.

- ASTM C1549- ³6WDQGDUG 7HVW 0HWKRG IRU 'HWHUPLQDWLRQ RI 6RODU
  Using a PortablH 6RODU 5HIOHFWRPHWHU´ (ASTM International, 2009)

Measurements with a portable reflectometer can be conducted on soiled samples by placing the instrument

An albedometer is typically made of two back-to-back pyranometers measuring solar radiation from 280 to 2800 nm **(Fig 17)**. It can be used only for outdoor measurement of any horizontal or low sloped surface. Clear sky conditions are needed, and solar elevation must exceed 45°. Typically, measurements are performed at 0.50 m over the target, and the surface area to be measured should exceed 4 m x 4 m, with one non-standardised method proposed by Akbari et al. (2008) to measure roof portions of 1 m x 1 m, even if not flat (e.g., tiled roofs).

Fig 17 An albedometer measuring a gravel roof. On the right, the detail of the two domes is shown.

Thermal Emittance

Thermal emittance (often referred to as emissivity) can be measured with calorimetric methods as in ASTM C1371 **(Fig 18)** or radiometric methods with portable instruments (as in EN 15976) or with an FTIR spectrometer with integrating sphere as in EN 12898. Two ASTM and two EN standards cover the topic.

- ASTM C1371- ³6WDQGDUG 7HVW 0HWKRG IRU 'HWHUPLQDWLRQ RI (PL 7HPSHUDWXUH 8VLQJ 3RU (ASTM International, 2015) HWHUV´
- (1 ³)OH[LEOH VKHHWV - 'HWHUPLQDWLRQ RI HPLVVLYLW\´ (CEN, 2011)
- E1 ³*ODVV LQ EXLOGLQJ 'HWHUPLQDWLRQ RI WKH HPLVVLYLW\´ (CEN, 2001)
- ASTM E408- ³6WDQGDUG 7HVW 0HWKRGV IRU 7RWDO 1RUPDO (PLW 0HWHH çVVPÀEX8V´Q

Fig 18 A portable emissometer. The image shows the sensing elements and the whole apparatus with the heat sink over which the samples are measured.

Natural exposure and laboratory exposure procedures

uses and mitigating urban overheating should be prioritised, especially because global warming leads to further increasing cooling needs.

Since cool roofs reduce the building energy needs, mitigate urban overheating and offset CO_2 emissions (Akbari, Menon, et al., 2008), ideally, the initial (unaged) solar reflectance and thermal emittance of all flat and low sloped roofs should be as high as technologically achievable. This corresponds to solar reflectance and thermal emittance values both in the neighbourhood of 0.90 (or SRI = 114). However, this is not possible for a variety of practical reasons, such as the need to retain the possibility of using a given type of roofing products categories, which for their geometry, cannot deliver extremely high solar reflectances. Another reason is to avoid only white roofing in areas where different roof colours are still required for architectural heritage motivations.

The minimum aged solar reflectance for pitched roofing is a value based on California Title 24 and ASHRAE, incremented by 0.05, which is not producing glare issues in low rise residential developments. Further, it is possible to find a wide palette of colours with high near-infrared reflectance for that solar reflectance range. The value for unaged and aged pitched roofing is the same because, in that solar reflectance range, soiling has minimal effects leading to no substantial depreciation in albedo over time (Paolini et al., 2014; Sleiman et al., 2011, 2014).

The minimum thermal emittance is based on the California Title 24 and ASHRAE requirements. The rationale is that 0.75 is an attainable value by most roofing products, including factory applied coating on metal roofing. Thermal emittance is largely unaffected by ageing in independent campaigns in the US and EU (Paolini et al., 2020; Sleiman et al., 2011, 2014).

The minimum solar reflectance after ageing (3 years) is computed with the formula given by California Title 24 to estimate aged values, considering field-applied coatings (the most unfavourable case). The formula allows computing the aged solar reflectance as

$$SR_{aged,calculated} = (0.2 + ß\ [SR_{initial} \pm 0.2])$$

Where SRinitial is the initial (unaged) solar reflectance and ß is an empirical coefficient equal to 0.65 for field-applied coatings and 0.70 for all other products. This formula was originally derived out of a database developed by the US EPA.

This formula has been found to be a conservative (pejorative) estimate of the long-term reflectance considering natural exposure in US climate contexts with only polluted Chinese and European urban areas causing more significant albedo losses (Paolini et al., 2014, 2020; Shi et al., 2019).

At present, no systematic information on the influence of weathering, soiling and biological growth on the solar reflectance of roofing materials is available for Australian cities.

The application of the Title 24 formula delivers the opportunity to have the first set of thresholds before a natural exposure program is established. The third stage (foreseen for NCC2031 or 2034) considers a fully developed ageing program in Australia with efficient anti-soiling cool roof technologies, which are already available on the market at this point, as it can be appraised in the rated products directory of the CRRC (Cool Roof Rating Council, 2022).

Proposal 10. Mould and condensation risk redu ction . To minimise the risk of mould and condensation with a high albedo, Section F part F6 should include as a Deemed to Satisfy Provision a general assessment by the low-risk investment and its financing at low rates can support the achievements of environmental and other indirect benefits.

The analysis of existing incentives adopted overseas (conducted in Part 1 of this project) highlighted that the most straightforward incentives schemes fall in one or a combination of these categories:

- Tax deductions. A fraction or the whole energy efficiency investment can be deducted from the income tax,

- Protect and support the cool roofs industry. The testing and accreditation system protect the Australian industry from untested products or untrustworthy competitors, who may provide unreliable certificates (either from in-house testing or unaccredited labs, maliciously or not). The industry works together with Government and Research Institutions to achieve consensus on the testing and accreditation infrastructure.
- Enforce compliance with the National Construction Code and simplifies its verification. A single reference point for testing and accreditation eliminates any ambiguity in the type of certificate that can be accepted for the product. Without the establishment of such testing & accreditation infrastructure and the indication of a single method to demonstrate suitability, it could be possible to achieve compliance with the NCC following one of the currently accepted options as in NCC A5.2 (Australian Building Codes Board, 2019):
    - A CodeMark Certificate of Conformity
    - A current cert.02.02 Tf 1 0m .92 reo.72 p/F2 10.0/008871 0 595.32 841.92 re ore W* n [(.)-1-110(the)-109(

ensures that the ACRC adopts consensual documents consistently referred to by the industry and that the industry has constant input in the success of the ACRC.

Pillar 2 ±Accreditation of testing laboratori es. Testing laboratories are accredited according to ISO 17025 and are accredited with the ACRC. If a lab is accredited according to ISO 17025 but is not accredited with the ACRC, certificates cannot be accepted in Australia. A notable exemption could be the acceptance of certificates issued by laboratories accredited with the US CRRC and ECRC, only for unaged values or rapid rating (as defined below in Pillar 6 ±Performance over Time). This is already the case for the ECRC, which accepts certificates from the US CRRC. Testing laboratories must be independent institutions.

Participating laboratories should participate in an interlaboratory round-robin exercise every five years. The accredited laboratories should use traceable reference samples for reflectance emissivity measurements, established in collaboration with metrology institutes. The scope of interlaboratory comparisons is to establish the measurement uncertainty and improve the measurement practice among accredited laboratories (Sleiman et al., 2015; Synnefa et al., 2013).

The accreditation criteria set by the US CRRC are given below. Similar accreditation criteria, to be discussed upon the establishment of the ACRC, are advised.

> Product testing for a product rating must be conducted by accredited-approved testing laboratories. The requirements for testing laboratory approval are:
>
> (A) The laboratory must submit a completed application and Test Lab Agreement for consideration as a recognised CRRC accredited testing laboratory, and pay the required fee;
> (B) At least one employee of the accredited testing laboratory must participate in a laboratory training workshop. This employee shall be designated as a Responsible Person for testing. All testing for product ratings shall be performed or supervised by the Responsible Person, who shall ensure that test results are reported in accordance with the defined requirements;
> (C) After participating in a laboratory training workshop, the laboratory must demonstrate competency prior to approval by completing testing on a set of specimens provided. The evaluation
>
> evaluate the existing data;
> (D) The laboratory must demonstrate ongoing competency by participating in Interlaboratory Comparison
> (E) The laboratory must not be an approved test farm or an affiliate of an approved test farm

Pillar 3 ±Factory Production Control . Independent testing can be conducted with accredited laboratories anonymously acquiring products on the market and performing tests. The scope of this activity is to ensure that implemented in Europe by EOTA (European Organization for Technical Agreements) for the systems covered by a European Technical Approval Guideline (ETAG).

Pillar 4 ±Support of Product Development . The testing procedures must be designed so that the results may support continuous product development, delivering improved performance to the Australian consumers and enabling the Australian industry to enhance its competitiveness domestically and overseas. Some testing infrastructures adopt pass/fail test procedures that cannot be used for product development and are therefore only a cost to the industry, without any feedback on the performance. The closer the testing procedure is to the real-world application, the better information is delivered to the manufacturer, who can use it in product development. An example of a testing procedure that cannot be used in product development is that of ETAG004 (EOTA, 2013), which is used in Europe for some external insulation systems and includes hygrothermal testing and freeze-thaw but on different samples. However, it is the combined action of multiple agents that produces degradation (Daniotti et al., 2013). The ETAG004 testing phase is expensive as it includes.

Pillar 5 ±Test methods delivering repeatable and reproducible results . The test methods should deliver unequivocal, repeatable and reproducible results, avoiding confusion. For this reason, it is recommended to specify also the reference air mass that is less likely to produce differences in results with different test methods.

For solar reflectance measurements, the Air Mass 1 Global Horizontal solar spectrum as in ASTM E903 is

- Natural exposure
- Feedback from practice
- Interim testing

Natural exposure. The testing procedure must include natural exposure for no less than three years at accredited exposure sites. It is recommended to establish three national exposure sites across Australia, located in the following climate zones:

- Zones 1-2, such Brisbane, Cairns, or Darwin (CZ1 high humidity summer, warm winter; CZ2 warm humid summer, mild winter)
- Zones 5-6, such as Inner West or Western Sydney (CZ5 warm temperature; CZ6 mild temperate)
- Zones 3-4, such as Alice Springs, Dubbo or other inland areas (CZ3 hot dry summer, warm winter; CZ4 hot dry summer, cool winter)

An experimental campaign with exposure of the same products at multiple candidate sites is recommended to determine the representativity, difference in achieved results, and benefit. The site in zones 3 or 4 is to be assessed in terms of representativity and advantage. After preliminary screening, it might be concluded that it is more advantageous for Australia to have a test farm in zones 2, 5, and 6, rather than 1, 3, and 5, for instance.

In the United States, three sites have been selected and are currently in use: in Arizona, Florida, and Ohio. In Europe, instead, only two sites have been selected: in Modena, Italy and Sanary, France.

The site in Zones 1-2 would offer information on the performance over time of cool materials in hot and humid climates, with insight concerning mould growth. The site in Zones 5-6 would offer information on the response of cool materials to the conditions in temperate climates, with frequent rain and thermal shocks, while the site in zones 3-4 would offer information on the response in dry conditions, with mostly dust pickup.

The advised criteria to select and establish the sites are the following:

- Representativity of the conditions of application rather than the severity of the climate context. It is not meaningful to expose materials in the middle of an unpopulated area (e.g., desert) because of cheaper land for a test farm, where the climate conditions might be not representative of populated areas. It is the combination of ageing factors, including environmental pollution leading to soiling, that represents the most significant challenge for cool roofs, and should be therefore tested.
- Information useful for product development. The sites should offer different exposure conditions, helpful to identify degradation mechanisms and improve products. For instance, two sites in the same temperate

Finally, to overcome the interannual variability associated with natural exposure practices (Paolini et al., 2020), it is recommended to expose three series of products starting their exposure in subsequent years (e.g., in 2022, 2023, and 2024) and measure their solar reflectance after 36 months of exposure for each series. This increases the duration of a rating cycle but minimises uncertainty in rating due to climate and environmental variability.

(Sleiman et al., 2014). The laboratory exposure protocol would need to be tuned to mimic Australian exposure conditions (Paolini et al., 2020, after the Australian natural exposure program is established.

Data from natural exposure programs performed overseas must not be accepted for the Australian market.

Pillar 7 ± Public database . Measured values should be publicly accessible through a national database maintained on the website of the future Australian Cool Roofing Council (as done by the US CRRC or ECRC).

7KH GDWDEDVH LQ DGGLWLRQ WR WKH PDQXIDFWXUHU¶V FRQWDFWV D

x Time zero (unaged) solar reflectance, thermal emittance, and SRI
x Interim values (with rapid rating or early results from natural exposure, indicating the method)
x Aged values for each site and three-site average.

For construction in a given area (e.g., Darwin), it should be allowed to use the values provided for the relevant climate zone for the purpose of building energy simulations, which must be performed with aged values.

Pillar 8 ±ACRC labelling . The ACRC should label products, and the certificate should be traceable. The label should include a QR code with reference to the complete testing report and all metadata about the testing

Finally, we present proposals to establish a testing and accreditation infrastructure in Australia to protect and support the consumer, and foster the Australian cool roofing industry, also enabling the enforcement of the National Construction Code.

There should be an industry-led association governing the testing and accreditation infrastructure, supported by accredited and independent testing laboratories and factory production control. We identified and recommended test methods, also for natural and laboratory exposure practices. Finally, we advised the publication of a database of rated products, to be available to the consumer, designers and all stakeholders, and a clear and recognisable labelling system.

All these recommendations can be effective only if discussed with all the relevant stakeholders including the Australian cool roofing industry and local governments. In fact, the success stories of implementation documented in the United States and in Europe were built on consensus of the accreditation and labelling of products, without which the market cannot achieve credibility.

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Sleiman, M., Kirchstetter, T. W., Berdahl, P., Gilbert, H. E., Quelen, S., Marlot, L., Preble, C. v., Chen, S., Montalbano, A., Rosseler, O., Akbari, H., Levinson, R., & Destaillats, H. (2014). Soiling of building envelope surfaces and its effect on solar reflectance ±Part II: Development of an accelerated aging method for roofing materials. Solar Energy Materials and Solar Cells, 122, 271 ±281. https://doi.org/10.1016/j.solmat.2013.11.028

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World Meteorological Organization. (2018). Preliminary edition of the CIMO GUIDE (WMO No. 8). http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html

5. A[illegible] Q[illegible]. C[illegible]

Introduction

Dear cool roof stakeholder

This is a survey to gather the perspectives from Australian cool roof stakeholders regarding the barriers and recommendations in cool roof application. We have provided six categories of potential barriers we identified which you can choose from. We welcome you to provide any recommendations regarding each category of barriers and also any additional comments at the end. We appreciate your time, and your contribution would be of great value to us!

1. About you

	Please specify
Your name	
Company name	
Your email	

Financial Barriers (Multiple Answers)

- [ ] Lack of measurement and monitoring equipment
- [ ] Lack of traceable database
- [ ] Lack of knowledge
- [ ] Other (please specify): ______

9. Regarding these barriers, what recommendations do you have?

1. Recommendation 1 ______
2. Recommendation 2 ______
3. Recommendation 3 ______

Technical Barriers

10. Technical Barriers (Multiple Answers) *

- [ ] Installation complexity
- [ ] Challenges of installation on existing buildings
- [ ] Risk of failure (reduced performance)
- [ ] Maintenance complexities
- [ ] Other (please specify): ______

☐ Limited applicability under certain climatic condition

☐ Other (please specify):

13. Regarding these barriers, what recommendations do you have?

1. Recommendation 1
2. Recommendation 2
3. Recommendation 3

Your comments

14. If you have any additional comments, please specify here.

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