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COOL ROOFS COST BENEFIT ANALYSIS

Volume 14 - Barriers, Implementation Benefits and Drawbacks and Recommendations

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Contents

Executive summary

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:

Phase 1: Quantitative and qualitative analysis of Australian cool roof stakeholders' perspectives. In the first phase, 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 met the inclusion criteria. Study eligibility criteria were included studies on "cool roof" OR "reflective roof "+ "PV" OR "solar panel" OR "photovoltaic", focusing on the building or construction sector, in English and without time limitation. The key findings extracted from relevant studies are discussed, and finally, the conclusion, research gaps and future work are demonstrated.

Phase 3: Assessment of cool roof market potential and its effect on creating new employment in Australia. This phase estimates the total roof area, the annual roof installation, and the maximum and minimum installation cost in Australian states. Second, the potential number of direct, indirect, and induced jobs created by cool roofs application in Australia is evaluated.

Phase 4: Proposals for 2025 revision of the Building Code of Australia and testing and accreditation infrastructure. In the final phase, 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.

To summarise, this study will present a comprehensive overview of the existing barriers, implementation benefits and drawbacks in the application of cool roofs in Australia with the aim to develop recommendations for the NCC2025 revision.

Collectively, the following conclusions have been drawn:

- There is no government incentive or support for developers or builders to utilise/apply the heat reflective coating technology to their structures. The introduction and increase of financial support like incentives, subsidies and rebate systems from federal and state levels are strongly advocated.
- Due to the lack of supportive policy and standardised accreditation for cool roof products, the cool roof products which have been tested by reliable laboratories are not getting the credibility and recognition they deserve. All products should be tested or provide authoritative information set against a well-defined standard to be recommended by government authorities and have assistance in purchase and installation. The stakeholders have expressed the urgency and indispensability for the formulation and introduction of such policies and legislation, as well as the modification of current building code to accommodate the heat mitigation techniques like cool roof.
- The focus of further development and commercialisation of cool roof technologies and advancements on cost reduction and efficiency improvement is recommended. There should be a minimum requirement of durability, solar reflectance, thermal emittance, spread rate and other key parameters.
- The inadequate information sharing and communication among various levels of industries and between the industry and the public are hindering the progress. Stakeholders believe that better information sharing and improving public awareness of cool roof's benefits are both essential.
- White or light-coloured cool roofs can be aesthetically unacceptable in some design scenarios. The applicability of cool roof is further obstructed possible glare and limited applicability under certain climatic conditions. Stakeholders highlighted that the glare issue only exists under specific circumstances and proposed that it should be clarified by professionals to eliminate the unnecessary concern of publics. It was also recommended to promote aesthetics and mandate minimum standards of colour, which were considered mainly a marketing task.
- The efficiency of solar PV integrated with cool roof application depends on different criteria, such as microclimatic conditions, local development context, building context, cool roof design and PV panel configurations. Roof albedo was mentioned 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:
    1. the annual energy yield of PV increases by 0.71%-1.36%.
    2. the cool roof performance increases by 14%.
    3. The 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, albedo of the reference scenario, location of PV-cool roofs, type of building, and the scale of our atmospheric model (mesoscale or microscale).

- 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 for PV panels which might call “cool photovoltaics” (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.

- Proposal 5. Limits cannot be set back by Local Govemenents.
- Proposal 6. Different SRI for pitched and sloped roofs.
- Proposal 7. Explicit indication of standard test and calculation methods.
- Proposal 8. Standard test methods and calculation procedures part of the NCC.
- Proposal 9. Interim unaged and aged values for SRI limits.
- Proposal 10. Mould and condensation risk reduction.

▪ A testing and accreditation infrastructure is an essential tool to achieve several goals, such as protecting and supporting the consumer in decision making, supporting the cool roofs industry in Australian, and enable the enforcement of the National Construction Code, with a simple verification method. Also, it should be unequivocal, repeatable, and assist decision-making (at any stage of the construction process) and dispute resolution. Protect and support the consumer.

▪ The testing and accreditation infrastructure should be informed by the following pillars:
  - Pillar 1 – Industry-led association governing the testing and accreditation infrastructure, after the establishment of an Australian Cool Roofing Council.
  - Pillar 2 – Accreditation of testing laboratories.
  - Pillar 3 – Factory Production Control.
  - Pillar 4 – Support of Product Development.
  - Pillar 5 – Test methods delivering repeatable and reproducible results.
  - Pillar 6 – Performance over Time: measured of aged values of SRI, SR, and TE, after 3 years of natural exposure.
  - Pillar 7 – Public database of rated products.
  - Pillar 8 – Product labelling by the Australian Cool Roofing Council.

1. Cool Roof Application _ Barriers and Recommendations

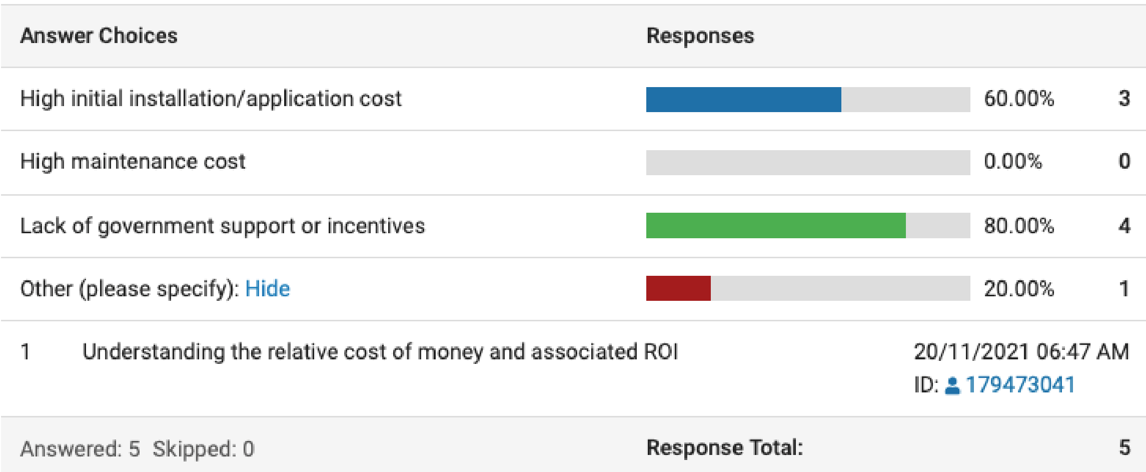
1.1 Introduction

To identify the barriers in the application of cool roofs in Australia and collect recommendations to address these barriers, a survey was created to gather the perspectives of Australian cool roof stakeholders (see **Appendix)**. Six categories of potential barriers were pre-identified for attendees to select from. Additional barriers shared by the stakeholders as well as the proposed recommendations to overcome the barriers, were collected. Five completed responses and two partially completed ones have been gathered and presented in this report.

1.2 Financial barriers and recommendations

The lack of government support or incentives for energy efficiency – as those available in the European Union, for instance – as well as the cool roof products and their implementation, has been identified by most of the stakeholders as a financial barrier in the cool roof industry, followed by the high initial installation/ application cost, as shown in

Figure 1. The maintenance cost is relatively trivial, and no one considered it as an obstacle in the application. The unawareness of the return of investment was also identified as a potential hindrance for homeowners to implement cool roofs.



Answer Choices	Responses		
High initial installation/application cost		60.00%	3
High maintenance cost		0.00%	0
Lack of government support or incentives		80.00%	4
Other (please specify): Hide		20.00%	1
1 Understanding the relative cost of money and associated ROI		20/11/2021 06:47 AM ID: 179473041	
Answered: 5 Skipped: 0	Response Total:		5

Figure 1 Financial barriers selected and reported by the cool roof stakeholders.

Regarding recommendations proposed by the stakeholders to overcome the financial barriers, the introduction and increase of financial support like incentives, subsidies and a rebates system from Federal and State Governments are strongly advocated, as shown in **Table 1**. Government funding for the equipment to conduct individual site studies has also been proposed.

Table 1 Recommendations proposed by the stakeholders to overcome the financial barriers and the corresponding votes each recommendation receives.

Category	Recommendations (Direct quotes from the collected responses)	Votes
Finance Based	Funding equipment hire for the duration of the individual site study by government.	1
	Government support and incentives akin to solar incentive program and awareness; National subsidy scheme provided by State & Federal government.	3
	Having a Rebate system provided by State & Federal Governments. Any or all of the above would seriously have a great take-up by all property owners, especially when they understand the large benefits.	1

1.3 Barriers in the industry and the recommendations

As shown in **Figure 2**, a lack of supportive policy and standardised accreditation has been spotted by all stakeholders as a huge barrier in the cool roof industry in Australia. The stakeholders have expressed the urgency and indispensability for the formulation and introduction of such policies and legislations, as well as the modification of the current building code to accommodate the heat mitigation techniques like cool roofs. Lack of client interest and acceptability also obstruct cool roofs from being widely applied. Insufficient understanding of the benefit of cool roof, together with the incomprehension about the cost performance of cool roof investment, is preventing the adoption of cool roofs in the roof market.

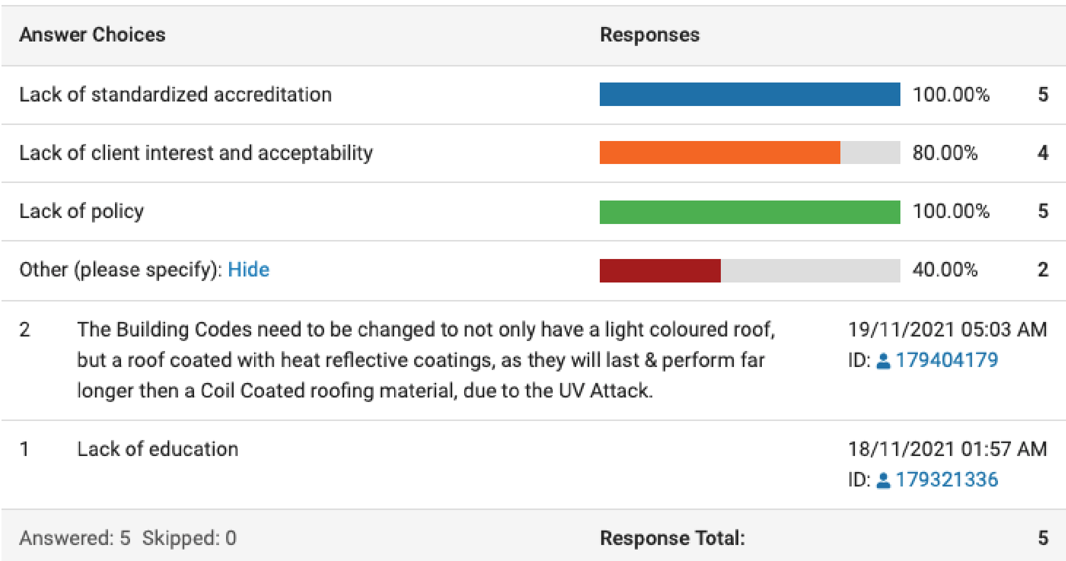


Figure 2 Barriers in the industry selected and reported by the cool roof stakeholders.

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 Application Cost with local variables specified for domestic dwellings and commercial properties, legislate all new builds and refurbs are to have the finish, and develop regulations to promote/regulate cool roofing are also strongly recommended by the stakeholders, as shown in ***Table 2***.

Table 2 Policy and legislation-based recommendations proposed by the stakeholders to overcome the related barriers and the corresponding votes each recommendation receives.

Category	Recommendations (Direct quotes from the collected responses)	Votes
Policy and Legislation Based	*NCC. Advocate for urban heat impacts to be included within the climate files used for NatHERS. Advocate for NatHERS to include a heat resilience component. Advocate for changes to NatHERS to consider the local micro-climate around the home from low solar absorptance materials and its impact on the efficiency of heating and cooling systems.*	3
	Attempt to have an agreed National Application cost for: Domestic Dwellings, & Commercial Properties.	1
	Low-cost government energy audit process. Auditing of the product claims and supporting proof.	2
	Australian Government to legislate all new builds and refurbs are to have reflective roofs (or other solutions with equivalent urban heat mitigation potential)	1
	Continue to encourage State and Local Governments development regulation to promote/regulate cool roofing.	1
	Establish a cool roof council based in Australia, similarly to what has been done in the USA and EU.	1

1.4 Product & technical barriers and the recommendations

In terms of products, the barriers pointed out by stakeholders are relatively scattered. The lack of cutting-edge technologies is one of the obstacles identified, which is mainly because the production of such materials requires high upfront capital to develop scaled-up production facilities. As shown in

Figure 3, features like insufficient weather resistance, inadequate reflectance or emittance, or low spread rate per litre are significantly hindering the products from gaining a greater market share. The lack of environmentally friendly products was not considered as a barrier. It should be noted that the lack of factual information on many product websites has been pointed out as a barrier to the standardisation cool roof market. This is highly related to the lack of standard specifications and certifications in the entire Australian cool roof market. Using different measurement methods, the data obtained based on different measurement environments can be inherently different. When the parameters of various products are not comparable, it is impossible for the evaluation, which is detrimental to the reliability of all products.

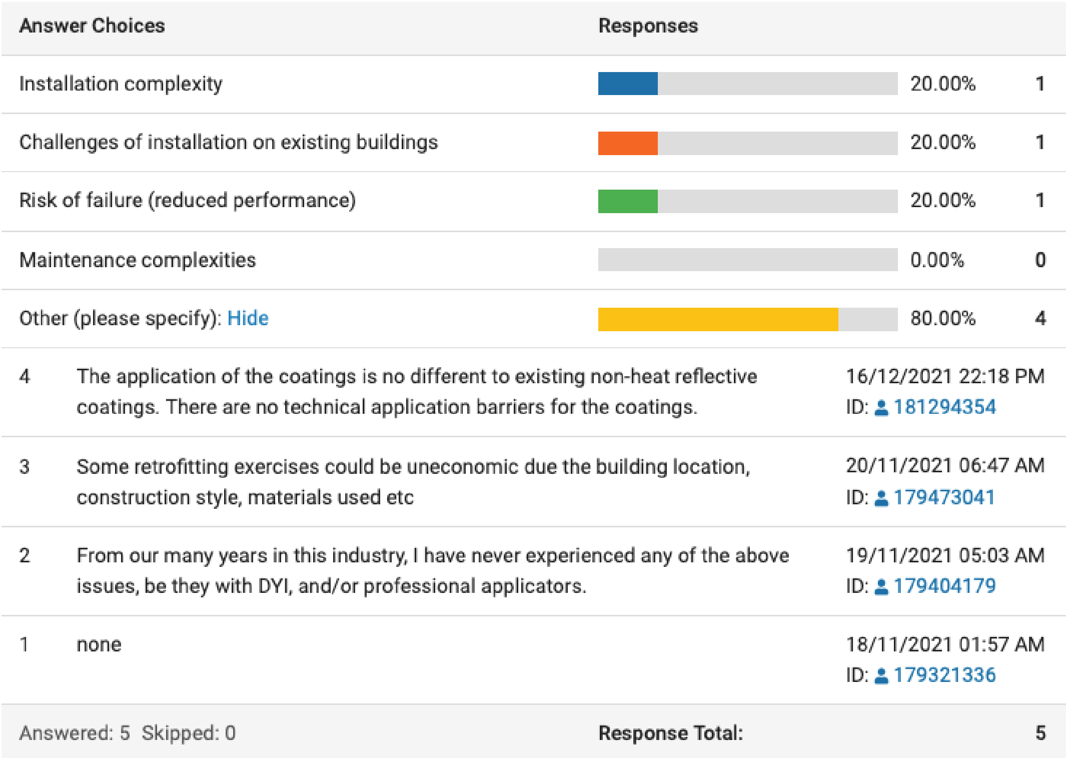
Answer Choices	Responses	
Lack of cutting-edge technologies	20.00%	1
lack of environmentally friendly products	0.00%	0
Lack of weather resistance	20.00%	1
Lack of superior reflectance or emittance	20.00%	1
Other (please specify): Hide	80.00%	4

4	Leading edge solutions often use costly materials and or require high upfront capital to develop scaled up production facilities.	23/11/2021 04:31 AM ID: 179604507
3	Lack of truth (factual information) in many product websites.	20/11/2021 06:47 AM ID: 179473041
2	Older technologies have very low spread rates per litre, which increases cost, labour, and weight. These should not be recommended.	19/11/2021 05:03 AM ID: 179404179
1	Our product is the highest accreditated in Australia. We do not face any of the above listed issues, but providing education and proving the product is viable without standardised tests had been our biggest hurdle.	18/11/2021 01:57 AM ID: 179321336

Answered: 5 Skipped: 0 Response Total: 5

Figure 3 Product related barriers selected and reported by the cool roof stakeholders.

Technically, installation complexity, challenges of installation on existing buildings, and the risk of performance deterioration are barriers selected by some individual stakeholders, as shown in **Figure 4**. But these technical barriers do not appear to be universal. The barrier to retrofitting is mainly an economic issue instead of a technical one. Some stakeholders stated that they have never experienced any of these technical issues in all their years in this industry.



Answer Choices	Responses		
Installation complexity		20.00%	1
Challenges of installation on existing buildings		20.00%	1
Risk of failure (reduced performance)		20.00%	1
Maintenance complexities		0.00%	0
Other (please specify): Hide		80.00%	4
4	The application of the coatings is no different to existing non-heat reflective coatings. There are no technical application barriers for the coatings.	16/12/2021 22:18 PM ID: 181294354	
3	Some retrofitting exercises could be uneconomic due the building location, construction style, materials used etc	20/11/2021 06:47 AM ID: 179473041	
2	From our many years in this industry, I have never experienced any of the above issues, be they with DYI, and/or professional applicators.	19/11/2021 05:03 AM ID: 179404179	
1	none	18/11/2021 01:57 AM ID: 179321336	
Answered: 5 Skipped: 0	Response Total:		5

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	**Recommendations (Direct quotes from the collected responses)**	**Votes**
Product and Technic Based	*That all topcoats be a Water-Based Coating and have a minimum Spread Rate of 5 m^2 per litre.*	1
	Provide clear guidelines on cool roof standardisation commensurate with the scale of the Australian market.	3
	Standardise minimum warranties/life cycles. Removing options that are shorter than 10 years will greatly impact long term maintenance issues, and consumption in the process.	1
	Further development and commercialisation of these technologies and advancements	1

	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.	1
	That any change to the building Codes requires such coatings to have the latest technology, where the spread rate is 5 m^2 per litre or above, which brings the cost down.	1
	Focus on efficient material and production costs. Target either post paint or conventional line applied coating processes.	1
	Whilst the best technical solution has value in academia, an improved paint systems that is economic and durable will likely have much greater direct practical impact than the best technical solution.	1

1.5 Knowledge and information barriers

All stakeholders regarded the lack of a traceable database to be a huge barrier to the development and improvement of cool roof products. Most of them also reported that the inadequate knowledge, as well as limited information acquired for the cool roof product due to the lack of measurement and monitoring equipment, is also obstructing the advancement in cool roof products, see **Figure 5** for details. One stakeholder has specified that some relevant knowledge and information are now accessible via various tertiary institutions. But most stakeholders are still unaware of such sources and still find the information difficult to obtain.

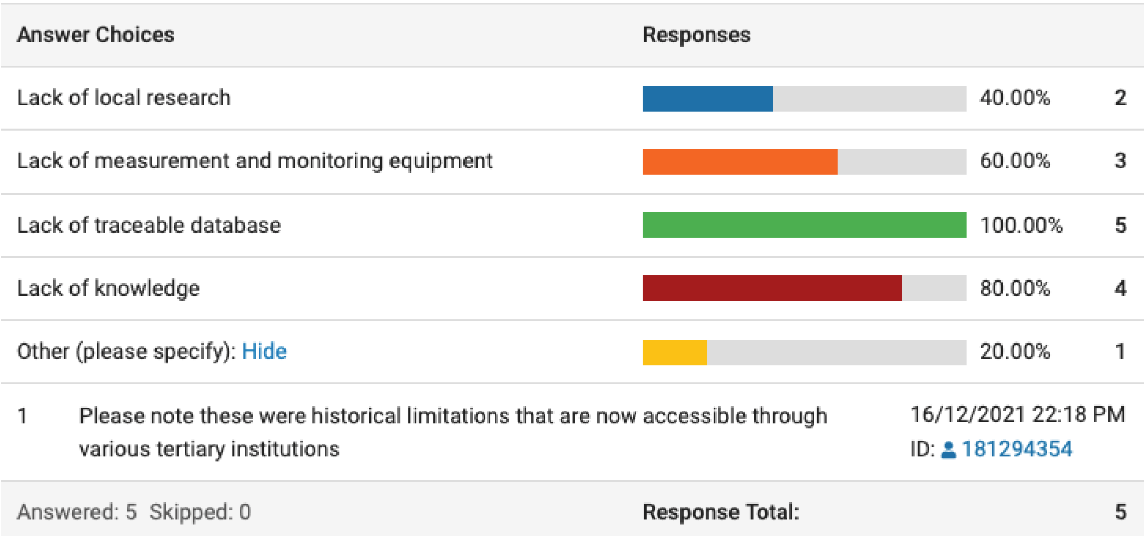


Figure 5 Knowledge and information barriers selected and reported by the cool roof stakeholders.

Stakeholders believe that better information sharing and communication is quite beneficial, see **Table 4**. For example, the establishment of a science-based comparative website, a cool roof database or a public information centre to share the characteristics, performance and energy saving outcomes of cool roof products or projects can drive progress across the industry. Developing targeted communication for different levels of the industry like regulators, builders, designers can also facilitate more efficient collaboration in implementing cool roofs. Meanwhile, improving the public awareness of cool roof's benefits is equally important. Public with increased knowledge about the long-term return on investment of cool roof adoption, both economically and environmentally, can act as an important catalyst to accelerate the market penetration of cool roofs.

Table 4 Knowledge and information-based recommendations proposed by the stakeholders to overcome the related barriers and the corresponding votes each recommendation receives

Category	**Recommendations (Direct quote from the collected responses)**	**Votes**
Knowledge and information Based	*A science based comparative product website.*	1
	Develop a cool roofing data base using a standardised system commensurate with the scale of the Australian market.	1
	Develop education packages suitable for Certificate and Degree training of cool roofing.	1
	Public information centre of above results.	1
	That a dedicated website be established for those buildings that are passive buildings that have had their roofs coated with the cool roof coatings and can make comments on the website about the performance of the coatings. That this website be available to the public/Governments & Councils etc	1
	Develop targeted communication for different levels of the industry (regulators, builders, designers)	1
	Increased knowledge base of available products.	1

1.6 Environmental barriers

Cool roofs, mostly being white or light coloured, are not accepted by residents, which is regarded as a serious barrier by 80% of the stakeholders, see **Figure 6**. Moreover, the reflected light can cause glare to the surrounding residents. 60% of the stakeholders also reported that the limited applicability under certain climatic conditions like the cool temperate climate of Tasmania, has hindered the applicability of cool roofs.

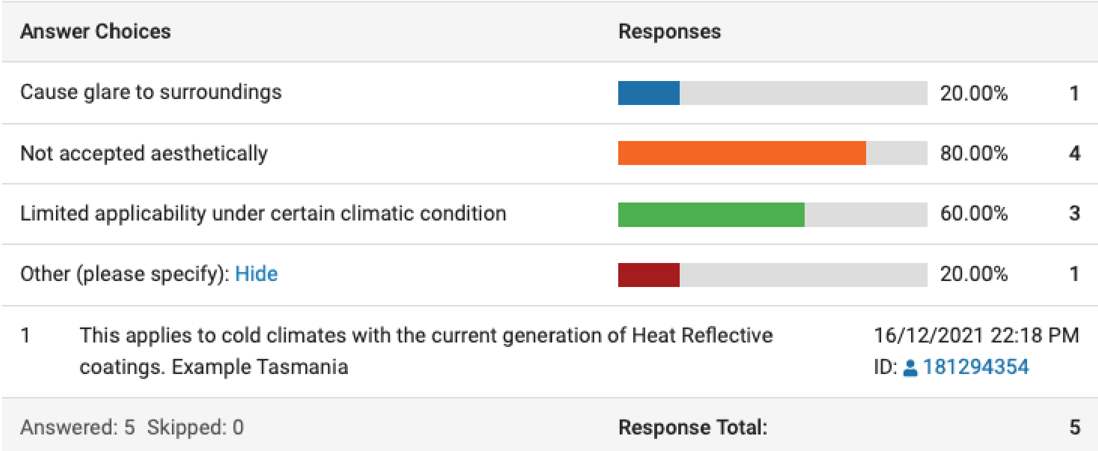


Figure 6 Environmental barriers selected and reported by the cool roof stakeholders.

Table 5 shows the environment-based recommendations proposed by the stakeholders to overcome the related barriers. Regarding the glare issue, it has been pointed out that commercial roofs (high set flat pitched) are not visually obtrusive. Areas where the concern is valid, i.e., above north facing pitched roofs, should be firstly identified and then solutions can apply, for example, low gloss, shielding, cool colours. They highlighted that the glare issue only exists under specific circumstances and proposed that it should be clarified by professionals to eliminate the unnecessary concern of publics. It was also recommended to promote aesthetics and mandate minimum standards of colour, which were considered mainly a marketing task. Some stakeholders also spotted that darker roofs shouldn't be asked to meet the Solar Reflectance Index requirements of white or light-coloured roofs. A perception shift in the general community would need to change.

Table 5 Environment based recommendations proposed by the stakeholders (to overcome the related barriers and the corresponding votes each recommendation receives.

Category	**Recommendations (Direct quotes from the collected responses)**	**Votes**
Environment Based	*Fact sheets on glare. E.g., commercial roofs (high set flat pitched) are not visually obtrusive. Identify areas where concern is valid - above north facing pitched roofs. Where it is an issue solution - low gloss, shielding, cool colours(i.e., materials with higher solar reflectance than standard materials having the same colour and thus appearance, because of increased backscattering in the near infrared wavelength range, which is not visible to the human eye).*	1
	Mandated minimum standards of colour, near-infrared reflectivity, etc.	1
	SRI values on our darker roofs do not compare to that of our white. But they are often asked for to fit in. A perception shift in the general community would need to change.	1
	Glare from such coatings is a Myth! The reality is that the rejected UV & IR Rays are scattered into the sky, not in one direction, where a Zincalume roof will give high Glare. This so-called Glare Myth, needs to be clarified by such professionals like those @ the UNSW to the general public and especially Councils throughout Australia.	1

	Promote aesthetics. This is perhaps a marketing task; however, we should promote light roofs promoted into beautiful inspirational homes.	1

1.7 Conclusions

The Australian Cool Roof industry has and is suffering from a lack of awareness, legislation, policy, and standards. In this report, major barriers in the Australian cool roof industry have been collected from the stakeholders and their recommendations to overcome the barriers have also been summarised. Key findings are listed as follows:

1. There is no government incentive or support for developers or builders to utilise/apply the heat reflective coating technology to their structures. The introduction and increase of financial support like incentives, subsidies and rebate systems from federal and state levels are strongly advocated.
2. Due to the lack of supportive policy and standardised accreditation for cool roof products, the legitimate and tested cool roofs are not getting the credibility and recognition they deserve. All products should be tested or provide authoritative academic information set against a well-defined standard to be recommended by government authorities and have assistance in purchase and installation. The stakeholders have expressed the urgency and indispensability for the formulation and introduction of such policies and legislations, as well as the modification of the current building code to accommodate the heat mitigation techniques like cool roofs.
3. The focus on further development and commercialisation of cool roof technologies and advancements in cost reduction and efficiency improvement is recommended. There should be a minimum requirement of durability, reflectance, emittance, spread rate and other key parameters.
4. The inadequate information sharing and communication among various levels of industries and between the industry and the public are hindering progress. Stakeholders believe that better information sharing and improving the public awareness of cool roof's benefits are both essential.
5. White or light-coloured cool roofs can be aesthetically unacceptable. The applicability of cool roof is further obstructed possible glare and limited applicability under certain climatic conditions. Stakeholders highlighted that the glare issue only exists under specific circumstances and proposed that it should be clarified by professionals to eliminate the unnecessary concern of the publics. It was also recommended to promote aesthetics and mandate minimum standards of colour, which were considered mainly a marketing task.

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, anthropogenic heat released in the cities, reduction of wind penetration due to the urban texture, and the lack of heat sources or sinks in cities (Khan and Asif, 2017; Santamouris et al., 2017b; Santamouris, 2019; Khan et al., 2020; Santamouris, 2020).

Several strategies have been studied to mitigate UHI and improve indoor thermal comfort (e.g., (Ma et al., 2018) and (Vahmani et al., 2016)). Santamouris et al. (2011) have reviewed several advanced cool materials systems to mitigate urban overheating. Such materials could be implemented on roofs to reflect more heat to the sky (high albedo, high emissivity), reduce absorbed solar radiation, change the rate of long-wave radiation remit to the atmosphere and delay the heat transfer toward the inside the building (thermal mass and phase-change materials). This mitigation technology, called cool roof techniques (high solar reflective), also known as “albedo effect”, is a passive solution reducing the cooling load and energy consumption of a building envelope due to its modified surface properties, such as albedo and emissivity (Synnefa et al., 2006; Altan et al., 2019). Cool roofs have also previously been shown to be a successful method for reducing summer overheating conditions to achieve global energy consumption reduction objectives. Research findings showed that daily peak surface temperature is 15 to 25 °C lower on cool roofs than darker roofs, which is even 5 °C lower than green roofs (Scherba et al., 2011; Fabiani et al., 2019; Cavadini and Cook, 2021).

A study by Santamouris et al. (2017a) analysed the mitigation potential of the known mitigation technologies based on performance data from about 220 real scale urban rehabilitation projects. Regarding using reflective materials installed on the roof of buildings or in pavements, the study's findings showed that the average peak temperature reduction was close to 1.3 K for all the projects. Almost half of the projects experienced a peak temperature reduction below 1 °C, and more than 80% fell below 2 °C. Similarly, a recent study Study on the cool roofs mitigation potential in Australia by Santamouris et al. (2021) showed that the outdoor air temperature in major Australian cities could be reduced by 2.1- 2.5 °C with solar reflective roofs – light coloured or cool coloured - which additionally reduce the cooling energy consumption of buildings. Likewise, Giordano et al. (2019) demonstrated that if white roof solutions spread worldwide in all cities, they could reach the targeted white reflective surface to eradicate the global warming effect. They found that it could save 10% on heating and cooling demand over a year on the building scale.

In general, using cool roofs (by implementing retro-reflective materials and reflective coatings) gives a various level of benefits:

1. At the urban scale, cool roofs reduce urban air temperatures by decreasing the quantity of heat transferred from roofs to the urban environment (Zinzi and Fasano, 2009; Zinzi and Agnoli, 2012; Santamouris et al., 2017a; Santamouris, 2020).
2. At the building level, cool roof application improves indoor thermal comfort, and it decreases energy bills by decreasing the usage of mechanical air conditioning systems (Pisello et al., 2013; Santamouris et al., 2021). Cool roofs allow for the saving of electrical energy throughout the building and eliminate the threat of voiding warranty claims. Cool roof application can decrease ~10–40% in air conditioning energy (Akbari et al., 2005; Synnefa et al., 2007).
3. In the long run, a lower temperature on the roof reduces maintenance and, therefore, extends its lifespan (Parker et al., 1998).
4. Cool roofs may also help improve the solar cells' efficiency in a Photovoltaic (PV) system for generating electricity (Yozwiak and Loxsom, 2010; Altan et al., 2019).

Most studies focused on the impact of a cool roof on the indoor comfort in buildings, which is a critical factor for building environments; however, equally, it is essential to quantify the other benefits such as the benefits through other active systems, i.e., solar technologies. While solar photovoltaic (PV) technology is known as a renewable energy technology that reduces greenhouse gas emissions, a recent systematic review study has shown that solar panels can significantly warm the urban environment during the day but typically cool the urban environment at night (Sailor et al., 2021). The study also found that this heating can also negatively affect the performance of PV solar panels. There are conflicting results about the impact of PV systems on the urban environment which can be due to errors and incorrect assumptions about PV systems and their function. In addition, PV panels can act differently in different climates, regions, building types and roof technology, such as integration of PV panels with cool roof technology. Therefore, there is a strong need to understand the interrelated attributes of cool technologies integrated with solar PV in different climates, regions, building types and assess their impact in a holistic way to inform government policy and development assessment.

To support this need, the aim of this report is to review previous research concerning the effectiveness of the application of the cool roof on PV panels efficiency. This study is performed to review previous research concerning the effectiveness of the cool roof application on solar PV efficiency. Specifically, the purposes of this report are:

1) To review the benefit of using cool roof technology when implemented at different scales
2) To outlines the key findings of the integrated roof by highlighting a set of interrelated attributes and their impacts on the outdoor and indoor thermal environments, based on a literature review of existing research
3) To identify the most accurate method of measuring, examining and simulating PV panel efficiency
4) To classify effective criteria for the performance of PV systems and cool roof technologies

The report is organised as follows: **Section 2.1** explains the methods that were carried out for this report. It is described in four sections: selected eligibility criteria, information sources, literature search and study records, and calculation methodology. **Section 2.2** elaborates the calculation methods for the three most relevant articles. The review results are discussed in **Section 2.3**, focusing on key findings extracted from relevant studies. Finally, the conclusion, research gaps and future work are summarised in **Section 2.4**.

2.2 Methodology

2.2.1 Eligibility criteria

The following study characteristics were used as inclusion criteria for the review:

- Studies on “cool roof” OR “reflective roof “+ “PV” OR “solar panel” OR “photovoltaic”,
- Studies focused on the building or construction sector,
- Studies published in English, and
- Full text available.

2.2.2 Information sources

1. Search engines of Scopus from Elsevier, Web of Science from Clarivate and Google Scholar;
2. Snowballing from the included studies.

2.2.3 Literature search and study records

We used combinations of keywords and phrases related to cool roofs and PV solar panels to construct search strings:

- Search string for **SCOPUS** (search date 12/11/2021):
  (TITLE-ABS-KEY ("cool roof" OR "reflective roof") AND TITLE-ABS-KEY ("pv" OR "solar panel" OR "photovoltaic” OR “hpv”)) **[29 hits]**

- Search string for **Web of Science** (search date 12/11/2021):
  TS=("cool roof" OR "reflective roof") AND TS=("pv" OR "solar panel" OR " photovoltaic” OR “hpv”) **[16 hits]**

- Search string for **Google Scholar** (search date 01/12/2021):
  “cool roof” OR "reflective roof" AND "pv" OR "solar panel" OR " photovoltaic” OR “hpv” **[1,590 hits]**

Reviewer screened the results of Google Scholar search by looking at the top 20 hits from each year between 2006 and 2021 (300 hits screened in total, 01/12/2021).

All above search strings were applied to article titles, keywords, and abstracts. All records were exported to Citavi reference management software. After deleting duplicated records and the first screen, 35 articles were left, of which 30 of them was more relevant. Some articles and references were also identified by snowballing from the included studies.

The majority of the studies were conducted in hot and warm climates, and there are few studies conducted in the cold, mild, mediterranean, and temperate climates. The top three continents were: North America, Europe, and Asia (**Figure 7**). More than half of the articles were published between 2019 and 2021, which reflects that this topic is still emerging and developing.

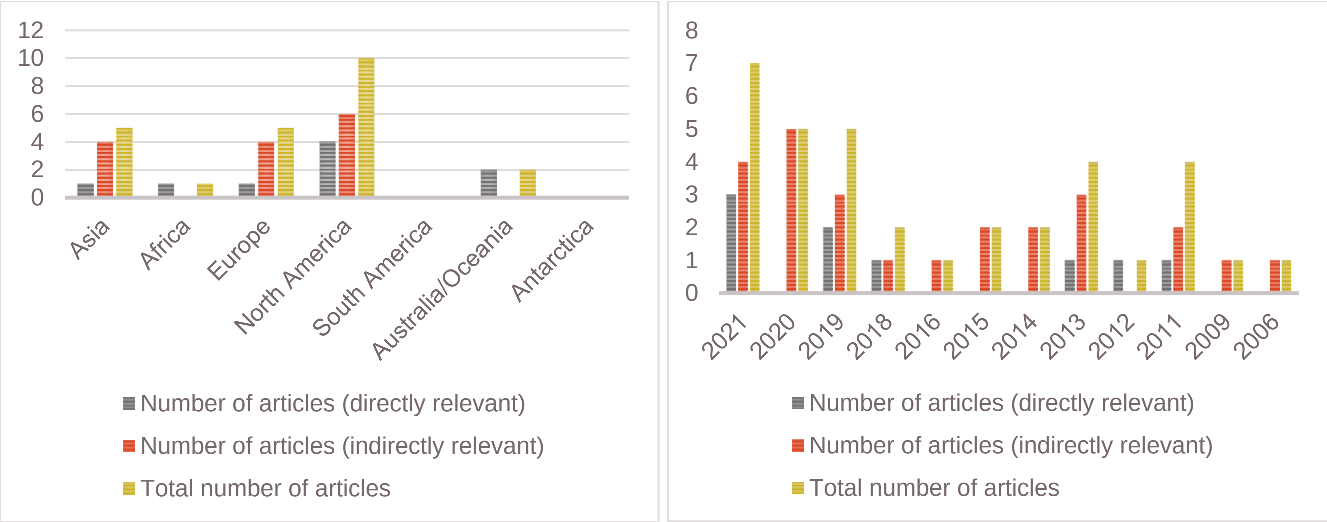


Figure 7 Number of papers from each continent and year

"Energy and Buildings" has been most active in this field by publishing almost 40% of selected papers, followed by "Solar Energy", "Energies", "Sustainable Cities and Society" and "Applied Energy" (**Figure 8**).

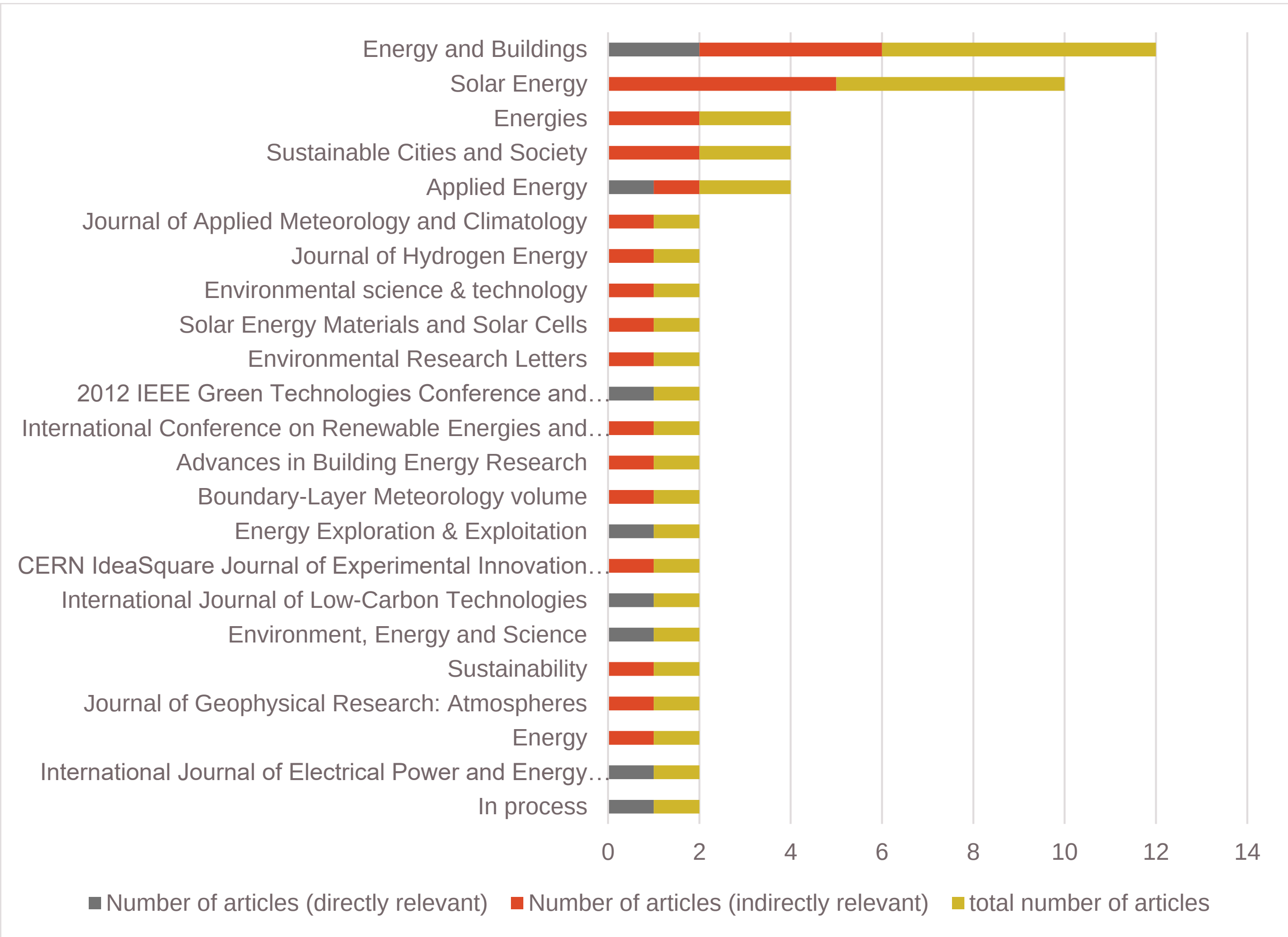


Figure 8 Number of papers published in relevant Journals or Conferences

Half of the articles employed theoretical research, and only 30% of articles used experimental methods which only 5 of them studied the integration of PV systems and cool roof technology (**Figure 9**). Overall, more than two-thirds of selected papers either focused exclusively on cool roof technology or PV systems, and only 10 of them conducted an integration of two systems.

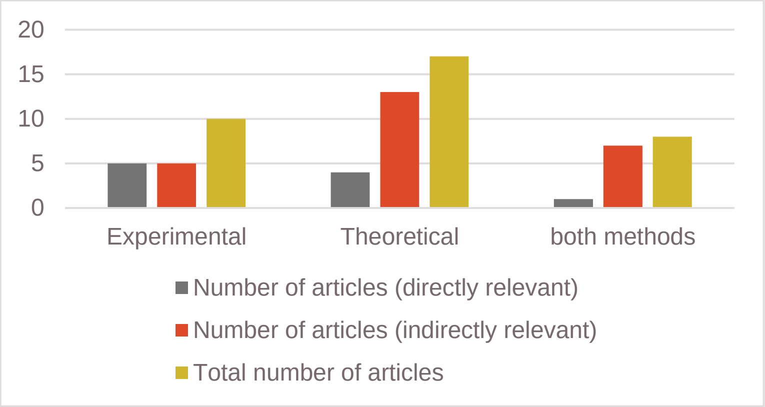


Figure 9 Number of papers published with respect to their employed methodology

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 were divided into "directly relevant" and "indirectly relevant". Then, the calculation methods for the most relevant articles were explained.

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

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
1	Australia	▪ To evaluate the current climatic conditions in major Australian cities, understand the characteristics of urban overheating ▪ To evaluate the magnitude and spatial variation of the mitigation /cooling potential of cool roofs when implemented at the city scale ▪ To investigate the impact of cool roofs on the cooling/heating energy needs and indoor air temperature for different building types of buildings in all capital cities.	Theoretical ▪ Meso-scale climate modelling ▪ Building energy simulations Building modelling	▪ Mortality increased by 5% for every 1 degree increase in daily maximum temperature. ▪ A city-scale deployment of cool roofs reduces the maximum peak ambient temperature by 2.1°C - 2.5°C, which means for every 0.1 increments of roof albedo, the ambient temperature decrease by 0.30-0.35°C. ▪ In existing (pre-code) buildings without or with low insulation levels, the cooling energy savings achieved with cool roofs are significant. For instance, the annual energy savings in a low-rise office building without insulation are 22.2-39.9 kWh/m^2 (34.7-42.3%) in Sydney, 4.0-9.7kWh/m^2 (12.3-27.6%) in Melbourne, and 34.2-52.2kWh/m^2 (33.8-39.4%) in Brisbane. ▪ In new buildings with high level of insulation (NCC 2019 DtS levels), the cool roofs savings are relatively less than that in old buildings. For instance, the annual energy savings in a new low-rise office building is 1.6-8.3 kWh/m^2 (4.6-18.2%) in Sydney, 0.2-1.0 kWh/m^2 in (1.2-4.6 %) Melbourne, and 3.4-5.2kWh/m^2 (4.6-6.0%) in Brisbane. ▪ In residential buildings: Indoor air temperatures in houses are also reduced by up to 4°C in new houses with high insulation (NCC 2019 DtS), with the number of hours exceeding 26°C reduced by even 100 hours per month (summer only) compared with a conventional solar absorptive roof.	(Santamouris et al., 2021)
2	-	▪ To review the relationship between photovoltaic energy production and the urban environment by emphasising on synthesis of what is known, what is the limitations and errors.	Theoretical	▪ The use of PV energy can significantly warm a city during the day, provide some cooling at night, and potentially increase energy consumption for air conditioning in some climates and types of buildings. ▪ PV systems in an urban setting are less efficient than those in rural areas, resulting in a 20% reduction in overall power production compared to PV applications in rural settings.	(Sailor et al., 2021)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
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 efficiency of 0.15% when cooling load was reduced by 0.5◦F/0.3 ◦C. ▪ 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	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
5	-	▪ To explain the role of urban surfaces in developing climate resilient and sustainable cities ▪ 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 ▪ Classification of urban surfaces ▪ Literature review: a collection of surface uses ▪ Categorisation and analysis of surface uses Identification of conflicts and synergies among surface uses	▪ The improvement of urban surfaces will provide opportunities to improve urban environments, social and economic resilience.	(Croce and Vettorato, 2021)
6	United States	▪ To evaluate the energy performance of an integrated adaptive envelope system (AES) applied to detached houses in four US climates. AES includes three main technologies: cool roofs, switchable insulation systems (SISs), movable PV-integrated shading devices (MPVISDs)	Theoretical ▪ Analysis of two extreme scenarios to understand the impact of PV panels on heating thermal loads, when deployed on a static cool roof ▪ Estimation of PV electricity output using EnergyPlus accounting for the MPVISD position	▪ Residential buildings can save a significant amount of energy through integrated AES. With the AES installed in a US home, they can almost achieve net-zero energy designs, especially in hot and mild climates ▪ Depending on the local climate, the integrated AES offers energy savings ranging from 234 kWh/year to 949 kWh/year.	(Dehwah and Krarti, 2021)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
7	-	▪ To describe and evaluate physical parameterisations accounting for the influence of “rooftop mitigation strategies (RMSs) on the urban environment in the context of the mesoscale model Weather Research and Forecasting (WRF)”	Theoretical ▪ Two-dimensional idealised simulations with the mesoscale WRF model in the urban environment	▪ During summer, cool and green roofs reduce near-surface air temperatures. ▪ A cool roof is the most efficient at reducing air temperature, followed by an irrigated green roof. ▪ Instead, photovoltaic panels cause a rise in temperature in the daytime and a slight decrease in the nighttime. ▪ Cool roofs are the most energy-efficient way to reduce the consumption of air conditioning. ▪ A green roof maintains a higher near-surface air temperature during the winter than clay tile roofs, thereby reducing energy consumption substantially. ▪ In the urban environment, the parameterisation schemes incorporated into the WRF model can be a valuable tool for evaluating mitigation strategies.	(Zonato et al., 2021)
8	Brampton, Ontario	▪ To investigate the trade-offs between large-scale deployments of rooftop PV, cool roofs, and street trees. ▪ To compare each intervention by examining the impact on the PV efficiency and the Universal Thermal Climate Index (UTCI) values.	Theoretical ▪ Simulation by 3D CFD model ENVI-met to address outdoor thermal comfort and PV energy efficiency	▪ large adoptions of rooftop PV instead of cool roofs can make outdoor environment 0.5 °C hotter during heatwaves ▪ Depending on their height and location, street trees can decrease the output of rooftop PV significantly. This points to the need for solar access laws, which are currently missing in Ontario.	(Berardi and Graham, 2020)
9	-	▪ To clarify whether PCM inclusions can help the membrane behave better over time due to the reduction of thermal stress.	Experimental	▪ A 25% PCM increase in weight optimises the surface finishing characteristics of the prototype, enabling a more stable thermo-optical behaviour, thus reducing both thermal-induced degradation and leakage.	(Fabiani et al., 2020)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
10		▪ To overview the materials compositions and nano/microstructures of radiative cooling technology. ▪ To summarise morphologies, substrates, properties, and performances of the selective emitting, back-mirror, reflecting, insulation, matrix, and dynamic switching materials	Theoretical ▪ Systematic review	▪ Using a combination of multiple layers and nanostructures is better for the design of radiative cooling composites from a materialistic perspective. ▪ An overview of nanomaterials and composite structures that can be used to optimise the design configuration for radiative cooling applications	(Li et al., 2020)
11	Mexico	▪ To analyse the typical envelope of industrial buildings in Mexico as well as the impact of industrial rooftop photovoltaic systems on annual energy consumption.	Theoretical ▪ Simulation using TRNSYS 17 USA to evaluate the thermal behaviour of the building over a year on an hourly basis	▪ Cool roof application on a non-insulated layer or simply insulating the roof is the best option for cities with warm climates. ▪ In warmer climates, rooftop PV systems would be most beneficial for industrial buildings with metallic roofs.	(Espino-Reyes et al., 2020)
12	Chennai, India	▪ To evaluate the performance of a Photovoltaic Thermal (PVT) collector-based hydrogen production system.	Experimental	▪ With an increase in flow rate, the collector outlet temperature, voltage, and power increase, while the PV module temperature decreases. ▪ For water-based PVT solar collectors with 0.011 kg/s flow rate at 12.00, the maximum thermal and electrical efficiency was 33.8% and 8.5%, respectively. ▪ With an increase in flow rate, the hydrogen yield rate will also increase. ▪ A fluid flow rate of 0.011 kg/sec at 12.00 results in the highest hydrogen yield of 17.1 ml/min. PV modules and water-based PVT with 0.011 kg/s mass flow rate at 12.00 have maximum and minimum cell temperatures of 73 °C and 58 °C, respectively.	(Senthilraja et al., 2020)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
13	Australia	▪ To assess the impact of solar PV and a/c Waste heat on urban heat island effects' along with an extension of the microclimate and Urban heat island mitigation decision-support tool	Theoretical ▪ Review of existing research ▪ Using advanced software, including PALM (Parallelised Large Eddy Simulation (LES) Model) and TRNSYS ▪ Using CRCLCL UHI-DS Tool to incorporate solar PV and A/C options for the UHI scenario analysis	▪ Solar PV and A/C waste heat can contribute to increased temperatures in the outdoor air ▪ A combination of UHI mitigation strategies, such as cool roofs, contributes to reducing outdoor air temperatures within cities and precincts.	(Ding et al., 2019)
14	Southern Arizona	▪ To perform a study to inform process-based understanding associated with PV systems. ▪ To develop observationally-based PV energy balance models to examine the climatic effects of large-scale deployment.	Experimental	▪ Within the array, daily maximum 1.5-m air temperatures were 1.38 °C warmer than in a desert site that has not been modified. ▪ PV modules surge nocturnal net longwave radiation loss ▪ Due to the increase in shortwave radiation absorption due to PV modules, the surface energy balance is amplified per surface plan area ▪ PV modules become the primary active surface, especially in the morning and afternoon. ▪ PV modules shift heat storage away from surface energy dissipation, make a vertically limited "warm layer" at approximately 1–2m above the ground, reduce surface storage heat flux release and increase sensible heat flux gain. ▪ PV modules keep warmer, neutral conditions below them.	(Broadbent et al., 2019)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
15	Sharjah, UAE	▪ To investigate the impact of cool roof applications integrated with solar PV panels for the Middle East climatic conditions	Theoretical ▪ Developing and modifying System Advisor Model (SAM) ▪ A rooftop energy balance model used to estimate the roof surface temperature, as input to the modified SAM model	▪ There is a possible impact of 5–10% improvement with the cool roof applications. ▪ Mainly climatology, geographical region and PV configrations affect the performance of PV systems ▪ 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 ▪ "Cool Carpet" case performe more effectively at 45 and 35 degrees as can be seen in the difference between the average of power difference. The average power difference at angle 45 is 2.9%, and at angle 35 it is 4.0%.	(Altan et al., 2019)
16	South Korea	▪ To evaluate and compare white and black roof with different Light Reflectance Value (LRV) and surface temperature	Experimental ▪ Using Unmanned Aerial Vehicles (UAVs) to evaluate the energy-saving performance of a cool roof.	▪ Whitish roof had LRV: 91.36, and rooftop surface temperature: 38.03 degrees C, and blackish color roof had LRV: 18.14, and rooftop surface temperature: 65.03 degrees C ▪ There was a strong negative correlation between the LRV and the surface temperature, implying that a higher LRV (e.g., a white color) is important in lowering the surface temperature.	(Park et al., 2019)
17	-	▪ To explores the potentiality of white roof as an effective solution to address global warming, urban heat island effect and energy consumption in buildings	Theoretical Experimental ▪ Literature review and prototyping	▪ Literature findings are used to investigate the effects of white roof technology on building energy efficiency.	(Giordano et al., 2019)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
18	-	▪ To review studies about roofing methods for flat roofs. Ten roofing methods are reviewed in this paper.	Theoretical ▪ Systematic literature review using the Web of Science database	▪ Suggestion of basic principles for selecting appropriate roofing methods. The right choice and the right implementation of these methods can eliminate the need for HVAC systems, while others can achieve a high degree of heat reduction. ▪ A wrong selection could result in mild to severe energy penalties.	(Abuseif and Gou, 2018)
19	Ghana	▪ To investigate the combined effects of roof coating and solar PV system in tropical region of Ghana	Theoretical ▪ Computational fluid dynamics simulation	▪ A coated roof reduces the building's temperature considerably, enhancing thermal comfort. ▪ A total of 427.670 MW h/year could be fed into the national grid with the participation of the solar photovoltaic module. ▪ The reduction in power generation costs can be achieved by combining a solar photovoltaic system with the roof coating.	(Opare et al., 2019)
20	United States	▪ To investigate the summertime regional impacts of cool roofs and rooftop solar PV deployment on cooling energy demand and near-surface air temperature and (for the two major Arizona cities of Phoenix and Tucson).	Theoretical ▪ Modelling system using the non-hydrostatic (V3.4.1) version of the Weather Research and Forecasting (WRF) model joined to the multilayer building energy (BEP+BEM) system	▪ A deployment of cool roofs and rooftop photovoltaic panels reduce near-surface air temperatures across the diurnal cycle and decreases daily citywide cooling energy consumption. ▪ During daytime, cool roofs provide better cooling than rooftop solar photovoltaic systems, but at night, solar panels are better at reducing the UHI effect. ▪ The maximum coverage rate deployment of cool roofs reduced citywide cooling energy demand by 13–14 %, while the rooftop deployment of solar photovoltaic panels reduced energy usage by 8–11 %. ▪ Deployment of both roofing technologies, cool roof and photovoltaic roof, have multiple benefits for the cities and urban environment.	(Salamanca et al., 2016)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
21	Greece	▪ To investigate the PV roof effect annually on building's energy demand (reducing the cooling and heating building loads) during different seasons	Theoretical Experimental	▪ 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. ▪ 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. ▪ 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	▪ 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	▪ 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. ▪ 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. ▪ Regarding primary energy, PVT technology offers higher overall efficiency than simple PV modules.	(Aste et al., 2015)
23	Greece	▪ To examine the shading and cooling effects of roof-mounted photovoltaics (PV)	Theoretical Experimental ▪ TRNSYS simulation	▪ PV panels have a significant effect on roof surface temperature between shaded and exposed portions of the roof during the summer. ▪ 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	-	▪ To review previous studies on water flat plate PV-thermal collectors	Theoretical	▪ 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)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
25	Yuma, AZ	▪ To demonstrate the impact of building-integrated photovoltaic roof on electricity production and cooling energy saving in office buildings.	Theoretical Experimental	▪ After installation of the BIPV, the roof's solar absorption decreased to 0.38 from 0.75, lowering summertime upper surface temperatures by about 5 °C. ▪ During summertime, the roof deck has a daily heat flux of +/- 0.1 kWh/m^2 as opposed to 0.3-1.0 kWh/m^2. ▪ BIPV significantly reduced daily heat flux from the ventilated attic to the conditioned space in the summer, suggesting a decoupled roof.	(Ban-Weiss et al., 2013)
26	Germany	▪ To analyse the operation in a daily office routine and to organise building's power supply and demand ▪ To analyse the impact of high reflecting roof coating on the photovoltaic efficiency and yield	Experimental	▪ A HR-coating (high reflecting coating) can increase the efficiency of building air conditioning and the benefit of renewable energy technologies. ▪ HR coatings have a higher albedo, increasing the yield of solar PV and solar thermal systems. ▪ A lower temperature on the roof surface has a positive effect on HVAC systems.	(Spitalny L, Unger D, Maasmann J, Schwerdt P, Van Reeth B, Thiemann A, Myrzik JM, 2013)
27	Taiwan	▪ To present an improved design strategies for metal sheet roofing in order to increase its thermal resistance ▪ To investigate Phase Change Materials (PCM) properties to absorb the downward heat flow and release it back to the environment	Theoretical Experimental ▪ Experimental and numerical analyses ▪ Mathematic equation system ▪ Solar simulation system	▪ Through the new design, it is possible to effectively reduce the downward flow of heat in the house from the roof. ▪ It was found that the phase change property of PCM could be utilised not only to store thermal energy, but also to enhance the thermal insulation effect of the combined PCM structure. ▪ This will result in a lower cooling load for the house and a reduction of the amount of electricity required for cooling.	(Chou et al., 2013)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
28	United States	▪ To evaluate the potential atmospheric impacts of solar PV deployment in meteorological modeling	Theoretical	▪ The simulations show that large-scale PV deployment has no adverse impact on air temperature or urban heat islands.	(Taha, 2013)
29	Edwardsville, Illinois	▪ To illustrates an experimental and comparative thermal analysis of two types of roofing membranes (reflective and non-reflective roofing membranes) matched with thin-film photovoltaic (PV) panels.	Experimental	▪ There is a difference in interface temperatures between thermoplastic olefin (TPO) and ethylene propylene diene monomer (EPDM)/PV assemblies, which could affect the degradation of the roofing material as well as the performance of the solar panels depending on the material used in fabrication.	(Irvine, 2012)
30	Portland Oregon	▪ To explore the impacts of sustainable roofing technologies on the rooftop energy balance, and sensible heat flux with a focus on the summertime urban heat island.	Theoretical Experimental ▪ Energy balance models were developed ▪ Simulation with EnergyPlus Experimental measurements	▪ Black roofs and black-PV roofs have the highest sensible heat flux to the environment, ranging from 331 to 405 W/m^2. ▪ An average of 11% less flux was produced by PV panels on black roofs compared to a white roof. ▪ The total sensible flux was substantially reduced when a black roof was replaced with a white or green roof. ▪ Compared to a black membrane roof, a PV-covered white or green roof reduced the total sensible flux by 50%	(Scherba et al., 2011)
31	United States	▪ To investigate the impacts of modifying surface albedo on regional climate and radiative effects produced by mass deployments of cool surfaces and photovoltaic arrays across the United States.	Theoretical Experimental ▪ Weather Research and Forecasting (WRF) model version ▪ Experimental measurements	▪ Implementing and using cool roofs and pavements resulted in domain-wide yearly average outgoing radiation to increase by 0.16 +/- 0.03 W/m(-2) (meaning +/- 95% C.I.) and afternoon summertime temperature in urban places was reduced by 0.11-0.53 degrees C. ▪ In reply to increased urban albedo, some rural locations demonstrated summer afternoon temperature rise of maximum +0.27 degrees C and these areas were closely connected with less cover of cloud and lower precipitation. ▪ Solar arrays had an impact on local and regional wind patterns within a 300 km radius.	(Millstein and Menon, 2011)

No	Location/ Climate of project	Research aim	Theoretical or experimental study	Findings	Reference
32	San Diego, California, United States	▪ To measure the thermal conditions across a roof profile partially covered with solar photovoltaic (PV) panels in San Diego, California	Theoretical Experimental	▪ A thermal infrared image taken on a clear April day showed the PV arrays to be 2.5 K cooler than the exposed roof during the day. ▪ Under the PV array, daytime roof heat flux was significantly reduced. ▪ During the night, the solar arrays were warmer than the exposed roof, indicating that they acted as insulators. ▪ A PV covered roof did not reduce the annual heating load but did reduce annual cooling load by 5.9 kWh/m^2 or 38%. ▪ As a result of having reduced daily variation in rooftop surface temperatures under the PV array, energy savings and/or human comfort benefits are realised, particularly on older warehouse buildings with rooftop PV.	(Dominguez et al., 2011)
33	-	▪ To systematically analysis the contribution of roof design to avarage cooling load and to peak load reduction. ▪ To demonstrate the importance of high albedo, while sensitivityto R-value and E drops away as albedo rises.	Theoretical ▪ Using a series of equations to do comparision	▪ The peak cooling load can be dramatically reduced by switching to high albedo (low Asol) regardless of R-value, but especially at Rr1.63. ▪ As roof albedo and emittance rise, lower R-values offer little or no penalty in peak load benefits or overall energy savings associated with reduced cooling demand.	(Gentle et al., 2011)
34	-	▪ To understand the impact of radiative forcing and land use change ▪ To compare the amount of radiative forcing avoided by substituting PV with fossil fuels	Theoretical	▪ The avoided radiative forcing due to the substitution of PV for fossil fuels is approximately 30 times larger than the forcing caused by the modification of albedo. ▪ Albedo effect significantly reduces the climatic benefits of PV ▪ It is important that we know how to deploy solar PV, not how much to deploy	(Nemet, 2009)
35	Tianjin, China	▪ To assess the impacts of BIPV on the building's heating-and-cooling loads, by applying on four different roofs: namely ventilated air-gap	Theoretical	▪ PV roofs with ventilated air gaps are suitable for the application in summer due to the low cooling load and high PV conversion efficiency. ▪ Comparing PV roofs with ventilation air-gaps, the PV roof with ventilation air-gap has a long time lag and a small decrement factor, and it has an absorption coefficient of 0.4, the same as a cool roof.	(Wang et al., 2006a)

		BIPV, non-ventilated (closed) air-gap BIPV, closeroof mounted BIPV, and the conventional roof with no PV and no air gap.		▪ BIPV with a non-ventilated air gap can be more appropriate in winter because the PV roof has less heating load and the PV output is higher.	

2.3 Calculation methods

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

2.3.1 "Green and cool roof choices integrated into rooftop solar energy modelling": by Cavadini and Cook (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 contribution of rooftop type into account in predicting surface temperatures. For instance, to assess the feasibility of solar PV installations, stakeholders widely use the System Advisor Model (e.g., Mangiante et al., 2020 and Ghazali et al., 2017), which assumes that the rooftop surface temperature is equal to the ambient temperature. Such assumptions make it impossible to compare the energy yield of PV systems on green and reflective roofs. Due to this gap, a study by Cavadini and Cook (2021) have developed a method that "can be used by stakeholders to compare the energy yield of PV installations on different rooftop configurations, including traditional (black membrane or rock ballasted) and sustainable (green and reflective) roofs". They used two models to quantify the influence of the roofing configuration on rooftop PV energy yield, including: 1) A modified version of the SAM to simulate PV panel energy yield, and 2) A rooftop energy balance model to estimate the roof surface temperature, which is given as input to the modified SAM version

2.2.1.1 A modified version of the SAM to simulate PV panel energy yield

Standard SAM assumes that the rooftop surface temperature is equal to ambient temperature. The following equations were used for SAM calculation:

$$P_{out} = I_t * A_m * \eta_{OC} \quad (1)$$

Where (I_t) is solar radiation, P_{out} is the power output and refer to the product of available I_t, A_m is module area, and η_{OC} is the panel conversion efficiency at operating conditions which depends on the panel cell temperature.

$$\eta_{OC} = (\eta_{ref} * \ 1 - \beta * (T_{cell} - T_{ref})) \quad (2)$$

"Where η_{OC} is the panel conversion efficiency at operating conditions [-], η_{ref} is the panel conversion efficiency at reference conditions (usually an irradiance of 1000 $W\ m^{-2}$ and an ambient temperature of 25 $^\circ C$) [-], β is the temperature coefficient of the cell [$^\circ C^{-1}$], T_{cell} is the cell temperature [$^\circ C$], and T_{ref} is the ambient temperature at reference conditions [$^\circ C$]." (Cavadini and Cook, 2021)

As discussed above, the Standard SAM heat transfer model assumes that both the surface temperature and the temperature on the back of the panel are equal to the ambient temperature. However, the roof's surface temperature is higher than the ambient temperature, and heat is released from the ground beneath the panel, leading to an increase in the air temperature below. Additionally, the air on the back of the panel can be poorly ventilated and mixed with the ambient air. Because the roof surface temperature can be higher than the

[1] "System Advisor Model (SAM), developed by Neises et al. (2012) , is an open source software, is widely used to evaluate the technical and economic feasibility of renewable energy installations. To model rooftop solar energy installations, SAM implements a set of physically-based equations to consider the heat fluxes between the PV modules and the roof surface, which accounts for the influence of roof surface temperature and albedo on PV panel power output" Cavadini and Cook (2021).

ambient temperature, this assumption misestimates the amount of radiant and conductive heat flow towards the solar panel, especially during the radiation peak at noon. Consequently, it might lead to an overestimating PV power output due to the underestimation of PV cell temperature.

In order to address this gap, rather than using the conventional assumption that the roof's surface temperature equals the ambient temperature, a time series of surface temperatures is given as the input to the modified version of SAM. The following equations were used to the modified SAM calculation:

$$T_{back} = (T_{amb} - T_s) * f_{conv} + T_s \quad (3)$$

Where T_{back} is the air temperature on the panel back [◦ C] used to compute the adapted convective heat flux. T_{amb} is the ambient air [◦C], T_s is the roof surface temperature [◦ C], and f_{conv} is the temperature factor [-], quantified how well the air behind the panel is mixed, which is specific to the PV installation.

According to temperature factor f_{conv}, it is assumed that the air temperature behind the panel (T_{back}) lies somewhere between the ambient temperature and the surface temperature of the roof. f_{conv} is an empirical factor that need to be adjusted for each PV installation. This factor depends on the slope of the panels, the distance between the panels and the roof and the ventilation on the roof. As an example, if f_{conv} is equal to 0, T_{back} is equal to T_s , signifying no mixing. Instead, if f_{conv} is equal to 1, it means that the back of the panel is well ventilated and the temperature is in equal to ambient air, similar to the standard SAM assumption (Cavadini and Cook, 2021). **Figure 10** illustrates an overview of the heat exchange on a rooftop with PV panels.

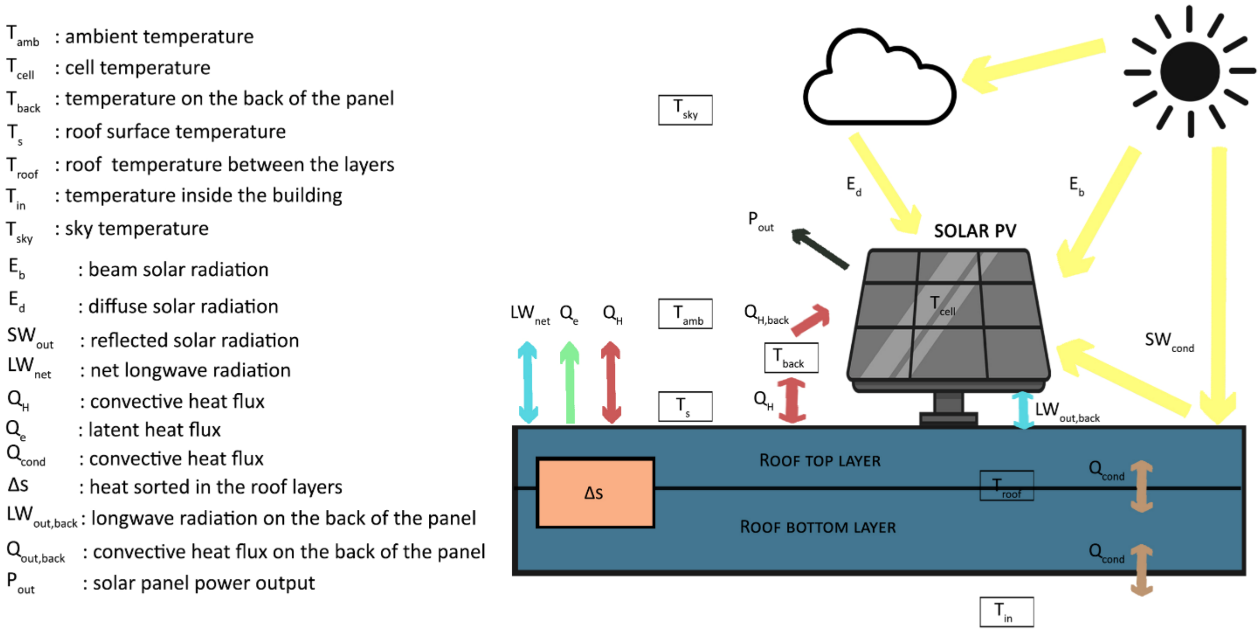


Figure 10 Overview of the heat exchange on a rooftop with PV panels. Source: Adapted from Cavadini and Cook (2021)

2.2.1.2 A rooftop energy balance model, used to estimate the roof surface temperature: as input to the modified SAM version.

A roof energy balance model, used for simulation of roof surface temperature, provides input for the modified SAM model. To provide input for the modified SAM, we need 6 general parameters describing roof characteristics and material proprieties: Roof area [m2], Albedo [α], emissivity [ε], Roof view factor, Ponding factor, Crop coefficient, and 4 specific parameters to each roof layer, and therefore considered for both top and bottom layers: Thickness (z), thermal conductivity (λ), heat capacity (C_p), and density (ρ).

Cavadini and Cook (2021) started model calibration and validation by modelling two same layers, including a bottom concrete layer and a top covered layer with different materials: either membrane (black or cool roofs), gravel (rock ballasted), or soil (green roof). Roof surface temperature was measured with a FLIR C3 infrared camera in August 2020 in Dübendorf, Switzerland. A visual observation, assessment and comparison of the simulations of the roof surface temperature aligned with an evaluation of several goodness of fit measures (GOF) was used to calibrate the roof energy balance model. They also quantified the error by computing GOF measures which included “root mean square error” (RMSE), “mean biased error” (MBE), “squared correlation coefficient” (r2) and total error. They found 7.8% as total error for the adapted SAM version in their study, which was ± 3% larger than the model accuracy of the SAM validation report by Freeman et al. (2013). The distance between the PV installation (in Dübendorf) and the weather station (in Kloten) , lack of calibration for shading, energy losses and module degradation rate can be one of the reasons for this difference (Cavadini and Cook, 2021). An improved calibration may reduce this overestimation; however, the adapted SAM version simulates the power output of the rooftop PV installation more accurately than the standard SAM model. The Adapted SAM model reduced the total error from 12.0% to 7.8% in this study.

In summary, the result of the above study showed that the adapted SAM model contributes to planners and stakeholders to compare the benefits of different rooftop configurations. Further work needs to be done to determine which sustainable roofing configurations should be implemented based on the climate zone and building type.

2.3.2 “An experimental study of the impact of cool roof on solar PV electricity generations on building rooftops in Sharjah, UAE”: by Altan et al. (2019)

An experimental method was used for this study by conducting a test on the laboratory rooftop of the University of Sharjah (UOS), in the UAE. In addition, PV-Analysator and PROFITEST PV were used to record the generation of electricity and to compile the analysis report for PV modules. Different type of cool coating paint was used to run experimental test. This experiment consisted of two scenarios, and each scenario had two cases. The first scenario compared two cases, one with the cool coating paint and the other one without the cool coating paint. As with the first scenario, the second scenario involves a black carpet.

In order to understand the impact of cool roof strategies on solar PV electricity generation and to test the potential improvement of PV yield and performance, different strategies were used in this study:

- Raising the diffused radiation onto the PV surface
- Choosing different tilt angles and giving one day for each tilt angle (45°,35°,25°, and 15°)

- Designing and fabricating a tailored panel's rack (in this study, they used a nylon sheet which was 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, particularly at the experiment's timeframe.
- "Cool Carpet" case perform more effectively at 45 and 35 degrees as can be seen in the difference 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 "Cool roof coating impact on roof-mounted photovoltaic solar modules at texas green power microgrid": by Rahmani et al. (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 modules on a metal roof with a white silicone coating. They also used "DC-coupled system that features nine 5 kW inverters each with maximum system input of 600Vdc and 92 batteries with 225.216 kWh energy storage". The daily/monthly voltages produced by the inverters, as well as the battery energy storage, have been monitored and authenticated through thermal modelling calculations. Further, the cool-roof effect on reducing the solar cell thermal voltage and module/roof heat flux was evaluated based on the conductive coefficient. More specifically, they used the following methodological approaches in their study:

- Modelling thermal analysis by installing the THERMAX under the individual modules in order to observe the impact of the cool roof technology on the performance of the solar arrays. THERMAX technique also formed and calculated the sol–air temperature and energy balance equations **(Figure 11)**

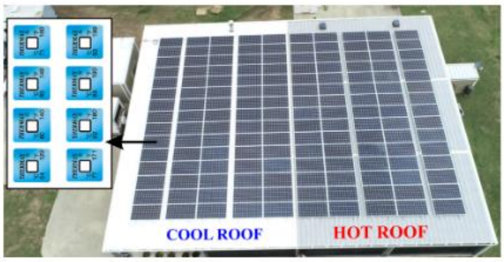


Figure 11 THERMAX technique (Thermax®) for thermal evaluation of the Rubicon buildings' roofs. (Rahmani et al., 2021)

- Analysing critical characteristics of the solar cells, such as the heat flux and the solar photovoltaic cell equations, so that modules can be arranged on the cool/hot roofs of case studies.
- Installing Tigo power optimiser at each module to observe the instantaneous performance of each solar module.
- Applying a power efficiency comparison between cool and hot surfaces, taking into consideration the maximum expected generation for each string, to verify the cooling load hypothesis.
- 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 (Rahmani et al., 2021)

Generally, this study had the following achievements:

- Sol-air temperature measurement showed an increase in system efficiency of 0.15% when the cooling load was reduced by 0.5◦F/0.3 °C.
- All critical characteristics of the module cell, such as voltage, current, power, and fill factor, were monitored and compared to the experimental B-grade modules. Using the aforementioned data, the diode, load, shunt, and reverse saturation currents of the cell were calculated.
- A 14.9% increase in overall efficiency was found from monitoring and verifying the weekly conversion efficiency with the theoretical equation.
- Project performances showed that 156.63 kWh of battery storage is enough to be able to continuously consume electricity for 5.55 hours or more after a blackout. The study shows an additional 10.41% of solar power and an extra 9.37% of current production when comparing cool and hot energy sources.
- The findings also compared ENERGY STAR® certified cool roof by changing cool roof characteristics and showed:
    - 26% improvement for cool roof by using initial Solar Reflectivity 0.87 versus 0.69
    - 23% improvement for cool roof by using aged Solar Reflectivity 0.80 versus 0.65
    - 9 times more heat retained by galvalume roof by Emissivity 0.10 versus 0.90
    - 77% improvement for cool roof by Initial SRI 110 versus 62 (Rahmani et al., 2021)

2.4 Results and Discussion

2.4.1 Sustainability of PV-cool roofs

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 1013 Wh per year, which would be about 0.5% of all building electricity usage (Akbari et al., 2005). It can also reduce the maximum peak ambient temperature by 2.1°C - 2.5°C in Australia, which means for every 0.1 increments of roof albedo, the ambient temperature decreases by 0.30-0.35°C (Santamouris et al., 2021).

In recent years, the consciousness of renewable energy and built environments has attracted photovoltaic scientists. The renewable and low-carbon solar energy resource has been strongly considered due to its availability, scalability, and technological maturity (Imani et al., 2018). The direct effects of PV systems include providing local power, while the indirect ones include reducing reliance on fossil fuels which lead to reduced emissions of greenhouse gas and other pollutants such as ozone precursors (Taha, 2013).

Therefore, the deployment of both cool roofing technology and photovoltaic systems has multiple benefits for cities and the urban environment. They can reduce near-surface air temperatures across the diurnal cycle and decreases daily citywide cooling energy consumption. However, cool roofs were mentioned as a more effective strategy than PV solar systems to reduce both daily cooling energy demand and near-surface air temperature (Salamanca et al., 2016). During the day, cool roofs reduced near-surface temperatures by 0.2–0.4°C, while solar photovoltaic panels reduced the temperature by 0.1–0.3°C (Salamanca et al., 2016). The maximum coverage rate deployment of cool roofs reduced citywide cooling energy demand by 13–14%, while the rooftop deployment of solar photovoltaic panels reduced energy usage by 8–11% (Salamanca et al., 2016).

The indirect impact of solar photovoltaic deployment on urban temperature depends on the average albedo of the city and PV energy conversion efficiencies. Some scholars, such as Taha (2013), demonstrated that the installation of solar PV systems has no negative nor positive effects on the air temperature of US cities with an average albedo of, e.g. 0.18, and even at low solar conversion efficiencies, e.g., 10%. However, some other scholars have shown that solar PV (with current energy conversion efficiencies) can significantly increase outdoor air temperature (Ding et al., 2019). A recent systematic review of 116 papers by Sailor et al. (2021) found that solar panels can dramatically warm the urban environment during the day but typically cool the urban environment at night. It is because the PV panels can only convert 16–20% of absorbed solar energy into electricity, and they cannot use all the absorbed energy, which will warm them up and create hot surfaces in the environment. It can warm the urban environment because the air passes over these hot surfaces, and it readily picks up the heat twice as effectively as if it were on a building surface or ground surface (Sailor et al., 2021). The study also found that this heating can also affect the performance of PV solar panels. Another experimental study measuring the surface energy balance above a utility-scale PV solar array, found that the “average daily maximum 1.5-m air temperature within the array was 1.38°C warmer than at an unmodified desert site” (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), some others said using “effective albedo” to analyse the correlation of PV modules, 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). In addition, using solar PV panels in the urban environment is challenging, and their positive/negative impacts depending on how we design, apply and maintain them?

2.4.2 Roof Integrated solar systems

A systematic literature review about roofing systems by comparing ten different roofing methods concluded that the integration of a variety of roofing systems could lead to the development of new roofing methods that would be worth further investigation; for example, photovoltaic panels can be integrated with other roofing systems like cool roofs and used as a secondary slab for double-skin roofs (Abuseif and Gou, 2018). This combination can reduce total heat gain by 30% (Kapsalis and Karamanis, 2015). It is also mentioned as a better strategy for the design of radiative cooling composites from a materialistic perspective (Li et al., 2020). However, there is a possible conflict between the application of reflective materials with the presence of active solar systems, which need further investigation (Croce and Vettorato, 2021).

The application of building-integrated photovoltaics[2] (BIPVs) is another integrated roof system that recently received more attention for its dual function (Dehwah and Krarti, 2021). BIPV acts as an additional layer to the building element and generates on-site electricity. A BIPV roofing system was assumed as another alternative to cool roof systems, for summer applications, due to their indirect shading impact and ability to produce electricity, especially with decreasing PV costs.

Water and air-based Photovoltaic Thermal (PVT) solar collectors were also mentioned as a solution to increase outlet temperature, output voltage and output power. The maximum thermal and electrical efficiency of water-based PVT solar collectors with 0.011 kg/s flow rate at 12.00, are 33.8% and 8.5%, respectively (Senthilraja et al., 2020). More importantly, PVT system can also decrease the PV module temperature with an increase in flow rate. PV modules and water-based PVT with 0.011 kg/s mass flow rate at 12.00 have maximum and minimum cell temperatures of 73 °C and 58 °C, respectively. Comparatively to the PV module, this PVT/water collector achieved the highest temperature reduction of 20.01% (Senthilraja et al., 2020). While they are still counted as hot surfaces, they are cooler than PV surface panels. Then, it can be concluded that PVT can be a better option for low-rise residential (mostly houses) instead of pure PV, despite the reduced conversion efficiency due to the module design.

2.4.3 Effects of roof Integrated Solar Systems on building energy demand

The BIPV system installation produces significant amounts of energy. According to a study by Ban-Weiss et al. (2013) in Yuma, Arizona, a PV module produced 0.15 kWh/m^2 of daily energy in winter and 0.4 kWh/m^2 in summer. Summer PV energy production was about 2.5 times higher than in winter. Overall, the BIPV system provided about 25% of the building's electrical energy use in summer and 20% in winter. Similarly, an

[2] In the BIPV system, thin films of PV are laminated to a white membrane layer, which is covered by a layer of 3.8 cm of insulation

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, grey $\rho = 0.2$), the BIPV can reduce the heat flux by 37%, whereas a cool roof with $\rho = 0.9$ can reduce the heat flux by about 50% (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 solar panels efficiency

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' performance depends on the amount of received solar radiation. Every 5^{o} 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 during the winter season. Then, the cool roof paint compensation changes the general understanding of the tilt angle of PV panels (Altan et al., 2019).

2.4.5 Albedo concept in cool roof technology

An increase in roof albedo (solar reflectance) can contribute to energy saving and reduce the cooling load in building, especially in hot climates. Research shows that raising albedo by 0.4 typically reduces total cooling demand by two to three factors but increase heating demand by only 10% or less (Gentle et al., 2011). The installation of reflective roof membranes can save energy by 40-60%, depending on the climate zone (Dominguez et al., 2011). It is because light coloured roof with a high albedo maintains a lower temperature in the sun as compared to dark coloured roofs (the black bitumen coating reached a temperature of 70°C, whereas the temperature of the cool roof is less than 30°C). However, energy savings will also depend on roof insulation. For example, as Simpson, JR and McPherson (1997) showed, the increase in roof albedo from 0.09 to 0.75 on a building without insulation resulted in a 28% savings in energy, but the increase from 0.30 to 0.75 on a building with R-30 insulation (a 5.28 Km2 W_1 increase in thermal resistance) only resulted in a 5% savings in energy.

Few studies have explored the impact of roof albedo on urban temperature, and they modelled and quantified the possibility of urban air temperatures reduction. A very early study by Sailor (1995) found that increasing the albedo over downtown Los Angeles by 0.14, can reduce peak summertime temperatures by 1.5°C. Similarly, a recent study by Santamouris et al. (2021) evaluated the current climatic conditions in major Australian cities. It showed that a city-scale deployment of cool roofs with higher albedo reduces the maximum peak ambient temperature by 2.1°C - 2.5°C in Australia. While some studies show the albedo concept in cool roof technology, there is little published data on the role of the albedo concept in PV-cool roofs.

2.4.6 Impact of cool roof application on solar PV efficiency

The albedo factor also impacts the efficiency of solar panels. A recent study by Cavadini and Cook (2021) used an updated SAM model (see Section 3.1) to identify how four roofing designs (white membrane, black membrane, rock ballasted, and vegetated) impact PV panel yield in Zurich, Switzerland. They demonstrated that green roofs could increase annual PV energy yield by 1.8%, while cool roofs with higher albedo can do so by 3.4%. The study also showed that the 95th-quantile roof surface temperature is inversely correlated with PV energy yield in the case study installation; an increase of 1°C results in a 71 kWh decrease in yearly energy output. In the same vein, Rahmani et al. (2021) did comprehensive thermal analyses in texas residential buildings, focusing on the cool roof-mounted solar photovoltaic system (see Section 3.3). They compared solar electric generation on both cool and hot roofs and found that the cool roof's performance was 1.31% higher. They also found that solar power efficiency in cool roofs increased by 10.4%, producing 294.6 kWh of solar power despite system losses and a 3.82◦F reduction in roof temperatures, resulting in a 1.91% increase in output power. Their study also proved that cool-roof application considerably enhances sustainable energy development, safety, and building comfort when applied worldwide.

Although some studies have shown the positive effect of PV-cool roofs on PV efficiency, some other studies demonstrated that the warming effect of PV panels on the surrounding environment during the day could negatively affect PV performance. When the surface temperature of solar cells increases, especially in hotter environments, their efficiency will be less (Sailor et al., 2021). It is due to the negative impact of heat on the temperature coefficient of PVs. According to Sailor et al. (Sailor et al., 2021), heat can reduce output efficiency by 10-25%. Some studies also suggest that installing PV above white roofs, with solar reflectance of 0.7, results in total warming of the urban airshed than dark roofs with a solar reflectance of 0.06 (Scherba et al., 2011; Sailor et al., 2021). Consequently, the efficiency of PV installed above the white roof can be lower. While these studies have emphasised the combination effects of roof coating and solar PV systems, the effect of cool roof’s materials on PV panel efficiency and the impacts of roof coating and solar PV systems are poorly understood (Li et al., 2020) and needs further experimental effort to address a generalisable findings.

Researchers suggested some ways to mitigate the negative impacts of PVs on the urban environment and also PV efficiency, such as: 1) designing panels that can more effectively reject heat that does not turn into electricity (Sailor et al., 2021), 2) high reflective coating for PV panels, calling “cool photovoltaics” (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 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 BIPV roofing system due to their indirect shading impact and ability to produce electricity, especially with decreasing PV costs (Dehwah and Krarti, 2021).

Overall, as **Table 6** showed, most studies until now have either focused exclusively on cool roof technology or PV systems. This is a result of siloed industries that tend to focus on selling each system to the customer. That is, solar roof installers do not have expertise in cool roof applications, and cool roof experts do not tend to focus on the benefits associated with photovoltaics. This presents an opportunity for research into the combined field of cool roof and PV systems, since there exists a natural overlap in the space. If more research on the benefits of this combination is conducted, government and industry partners may become motivated to increase incentives or establish mandates for such technology.

2.5 Conclusion and Future Work

According to the structural review of previous literature, the efficiency of solar PV integrated with cool roof application depends on different criteria, such as microclimatic conditions (ambient temperature, air pressure, humidity, precipitation, sunshine, sky temperature, beam solar radiation, diffuse solar radiation and reflected solar radiation), local development context, building context (building orientation, type, and design), cool roof design (roof surface temperature, roof temperature between the layers, shading, roof albedo, temperature inside the building, net long-wave radiation, convective heat flux, latent heat flux and heat sorted in the roof layers), PV panel configurations (panel tilt, panel slope, Solar PV type such as bi-facial or perovskite, distance from the roof, cell temperature, 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) (**Figure 12**). Therefore, cool roofs can boost solar panel yield by increasing solar radiation as long as proper materials and design strategies are employed.

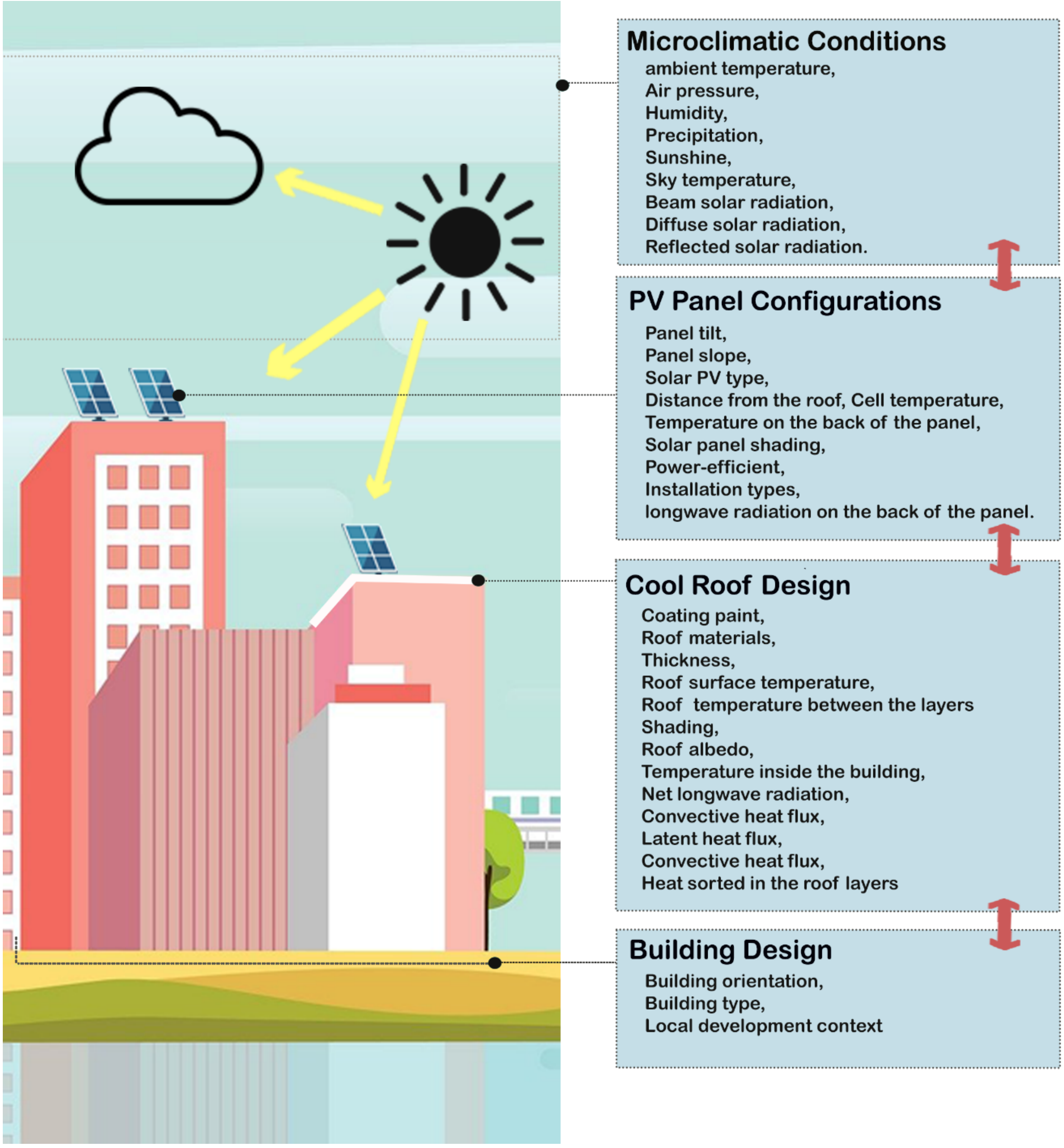


Figure 12 Criteria for evaluating the effectiveness of solar PV applications integrated with cool roofs application

In the present report, the effect of cool roofs on PV solar panels' performance has been investigated through 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 environmental benefits, including building energy savings and urban heat mitigation. However, the correlational relation between PV arrays and cool roofs are likely to vary across different climates, regions, , building and individual PV panels characteristics.
2. PV systems have significant impacts on urban aspects such as urban air temperatures, the provision of shade and building energy consumption.
3. 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)).
4. Although PV with a lower tilt angle have a higher performance during summer, and the systems with a higher tilt angle have a higher performance during the winter season, the compensation of the cool roof paint can actually change the general understanding of the tilt angle of PV panels.
5. The higher albedo of the cool roofs can decrease roof surface temperature. It can have positive or negative impacts on PV efficiency and solar thermal systems, depending on microclimatic conditions, local development context, building context, cool roof design and PV panel configurations.
6. The performance of PV technology in an 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 for PV panels, called “cool photovoltaics” (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 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 BIPV roofing system due to their indirect shading impact and ability to produce electricity, especially with decreasing PV costs (Dehwah and Krarti, 2021).

In summary, results from previous studies, especially in warmer regions, supported the need for integrated PV with sustainable roof evaluation methods such as cool roofs. However, there are several limitations that could be improved in future work:

1. There is a need to reduce the number of necessary input parameters of a rooftop energy balance model so that stakeholders can more easily integrate the energy balance model with the SAM model or other analysis models. (Cavadini and Cook, 2021). Therefore, more significant efforts are needed to design a more user-friendly model for the industry.
2. The modified SAM model was only tested for limited climate conditions, for a single PV type, and for limited installation types. The results may change with other models or in other climate regions and other PV and cool roof configurations. Then, continued efforts are needed to test analysis model in different climate zones and conditions.
3. Further research would be needed to identify different f_{conv} values (quantifies how well the air behind the PV panel is mixed) in order to consistently compare the output of PV installations with different design characteristics (Cavadini and Cook, 2021).

4. The majority of studies have either focused exclusively on the impacts of cool roof technology or PV systems on building indoor comfort and urban environment. Very little is currently known about the effects of integrated roof systems on both mesoscale and microscale.
5. As the microclimatic conditions and geographical conditions may change the efficiency of both PV panels and cool roof application, there is a need for testing the effectiveness of cool roof application on the efficiency of PV panels in different climate zone, including Australia. In addition, the current review study showed that there are few studies conducted on the cold, mild and mediterranean and temperate climates, most of which are conducted in hot and warm climates.
6. Previous studies examined limited PV types such as mono-crystallised PV cells, and therefore, there is a need for further studies using different PV panel configurations integrated with cool roofs application.
7. Further controlled empirical studies and validated modelling are needed to test different approaches to decrease PV cell operating temperature, and its effect on urban air temperature, building energy consumption and PV efficiency.

Overall, existing literature suggests that the future improvement of PV-cool roofs could generate more electricity and lead to air temperature reduction due to the significant reduction of excess heat release to the surrounding environment. The improvement could also result in a significant reduction of carbon emissions, reducing climate change on a larger scale. Hence, further research and government intervention options need to consider the specific microclimatic conditions, local development context, cool roof design and solar PV configurations when developing PV-cool roof.

2.6 References

Abuseif, M., Gou, Z., 2018. A review of roofing methods: Construction features, heat reduction, payback period and climatic responsiveness. Energies 11 (11), 3196.

Akbari, H., Levinson, R., Rainer, L., 2005. Monitoring the energy-use effects of cool roofs on California commercial buildings. Energy and Buildings 37 (10), 1007–1016.

Altan, H., Alshikh, Z., Belpoliti, V., Kim, Y.K., Said, Z., Al-Chaderchi, M., 2019. An experimental study of the impact of cool roof on solar PV electricity generations on building rooftops in Sharjah, UAE. International Journal of Low-Carbon Technologies 14 (2), 267–276.

Aste, N., Del Pero, C., Leonforte, F., 2014. Water flat plate PV–thermal collectors: A review. Solar Energy 102, 98–115.

Aste, N., Leonforte, F., Del Pero, C., 2015. Design, modeling and performance monitoring of a photovoltaic–thermal (PVT) water collector. Solar Energy 112, 85–99.

Ban-Weiss, G., Wray, C., Delp, W., Ly, P., Akbari, H., Levinson, R., 2013. Electricity production and cooling energy savings from installation of a building-integrated photovoltaic roof on an office building. Energy and Buildings 56, 210–220.

Berardi, U., Graham, J., 2020. Investigation of the impacts of microclimate on PV energy efficiency and outdoor thermal comfort. Sustainable Cities and Society 62.

Broadbent, A.M., Krayenhoff, E.S., Georgescu, M., Sailor, D.J., 2019. The observed effects of utility-scale photovoltaics on near-surface air temperature and energy balance. Journal of Applied Meteorology and Climatology 58 (5), 989–1006.

Cavadini, G.B., Cook, L.M., 2021. Green and cool roof choices integrated into rooftop solar energy modelling. Applied Energy 296.

Chou, H.-M., Chen, C.-R., Nguyen, V.-L., 2013. A new design of metal-sheet cool roof using PCM. Energy and Buildings 57, 42–50.

Chumpolrat, K., Sangsuwan, V., Udomdachanut, N., Kittisontirak, S., Songtrai, S., Chinnavornrungsee, P., Limmanee, A., Sritharathikhun, J., Sriprapha, K., 2014. Effect of ambient temperature on performance of grid-connected inverter installed in Thailand. International Journal of Photoenergy 2014.

Croce, S., Vettorato, D., 2021. Urban surface uses for climate resilient and sustainable cities: A catalogue of solutions. Sustainable Cities and Society 75, 103313.

Dehwah, A.H.A., Krarti, M., 2021. Energy performance of integrated adaptive envelope systems for residential buildings. Energy 233.

Descoeudres, A., Allebé, C., Badel, N., Barraud, L., Champliaud, J., Debrot, F., Faes, A., Lachowicz, A., Levrat, J., Nicolay, S., 2015. Silicon heterojunction solar cells: towards low-cost high-efficiency industrial devices and application to low-concentration PV. Energy Procedia 77, 508–514.

Ding, L., He, B., Petersen, H., Craft, W., Qi, J., Santamouris, M., Parasad, D., 2019. Assessing the Impact of Solar Photovoltaics and Air Conditioning Waste Heat on Urban Heat Island Effects.

Dominguez, A., Kleissl, J., Luvall, J.C., 2011. Effects of solar photovoltaic panels on roof heat transfer. Solar Energy 85 (9), 2244–2255.

Espino-Reyes, C.A., Ortega-Avila, N., Rodriguez-Munoz, N.A., 2020. Energy Savings on an Industrial Building in Different Climate Zones: Envelope Analysis and PV System Implementation. Sustainability 12 (4).

Fabiani, C., Piselli, C., Pisello, A.L., 2020. Thermo-optic durability of cool roof membranes: Effect of shape stabilized phase change material inclusion on building energy efficiency. Energy and Buildings 207, 109592.

Fabiani, C., Pisello, A.L., Bou-Zeid, E., Yang, J., Cotana, F., 2019. Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance. Applied Energy 247, 155–170.

Gentle, A.R., Aguilar, J.L., Smith, G.B., 2011. Optimized cool roofs: Integrating albedo and thermal emittance with R-value. Solar Energy Materials and Solar Cells 95 (12), 3207–3215.

Giordano, F., Tulumen, Z., Sanchez, R., Magnacca, G., 2019. White roof as a multiple benefits low-cost technology: a state of the art. CERN IdeaSquare Journal of Experimental Innovation 3 (2), 12–17.

Hasan, A., Alnoman, H., Rashid, Y., 2016. Impact of integrated photovoltaic-phase change material system on building energy efficiency in hot climate. Energy and Buildings 130, 495–505.

Imani, M.H., Niknejad, P., Barzegaran, 2018. The impact of customers' participation level and various incentive values on implementing emergency demand response program in microgrid operation. International Journal of Electrical Power & Energy Systems 96, 114–125.

Irvine, G. (Ed.), 2012. Thermal comparison of reflective and non-reflective roofs with thin-film solar panels.

Kant, K., Anand, A., Shukla, A., Sharma, A., 2020. Heat transfer study of building integrated photovoltaic (BIPV) with nano-enhanced phase change materials. Journal of Energy Storage 30, 101563.

Kapsalis, V., Karamanis, D., 2015. On the effect of roof added photovoltaics on building's energy demand. Energy and Buildings 108, 195–204.

Kapsalis, V.C., Vardoulakis, E., Karamanis, D., 2014. Simulation of the cooling effect of the roof-added photovoltaic panels. Advances in Building Energy Research 8 (1), 41–54.

Khan, H.S., Asif, M., 2017. Impact of green roof and orientation on the energy performance of buildings: A case study from Saudi Arabia. Sustainability 9 (4), 640.

Khan, H.S., Paolini, R., Santamouris, M., Caccetta, P., 2020. Exploring the synergies between urban overheating and heatwaves (HWs) in western Sydney. Energies 13 (2), 470.

Kibria, M.A., Saidur, R., Al-Sulaiman, F.A., Aziz, M.M.A., 2016. Development of a thermal model for a hybrid photovoltaic module and phase change materials storage integrated in buildings. Solar Energy 124, 114–123.

Li, W., Li, Y., Shah, K.W., 2020. A materials perspective on radiative cooling structures for buildings. Solar Energy 207, 247–269.

Ma, S., Pitman, A., Yang, J., Carouge, C., Evans, J.P., Hart, M., Green, D., 2018. Evaluating the effectiveness of mitigation options on heat stress for Sydney, Australia. Journal of Applied Meteorology and Climatology 57 (2), 209–220.

Mamun, M.A., Islam, M.M., Hasanuzzaman, M., Selvaraj, J., 2021. Effect of tilt angle on the performance and electrical parameters of a PV module: comparative indoor and outdoor experimental investigation. Energy and Built Environment.

Masson, V., Bonhomme, M., Salagnac, J.-L., Briottet, X., Lemonsu, A., 2014. Solar panels reduce both global warming and urban heat island. Frontiers in Environmental Science 2, 14.

Millstein, D., Menon, S., 2011. Regional climate consequences of large-scale cool roof and photovoltaic array deployment. Environmental Research Letters 6 (3).

Nemet, G.F., 2009. Net radiative forcing from widespread deployment of photovoltaics. Environmental science & technology 43 (6), 2173–2178.

Oh, J., TamizhMani, G., Palomino, E. (Eds.), 2010. Temperatures of building applied photovoltaic (BAPV) modules: air gap effects. SPIE, 33-43.

Opare, W., Kang, C., Gu, Y., Mao, N., 2019. Combination effects of roof coating and solar photovoltaic system in the tropical region of Ghana: A case study. Energy Exploration & Exploitation 37 (5), 1455–1476.

Park, S.-I., Ryu, T.-H., Choi, I.-C., Um, J.-S., 2019. Evaluating the Operational Potential of LRV Signatures Derived from UAV Imagery in Performance Evaluation of Cool Roofs. Energies 12 (14), 2787.

Parker, D.S., Huang, Y.J., Konopacki, S.J., Gartland, L.M., 1998. Measured and simulated performance of reflective roofing systems in residential buildings. ASHRAE transactions 104, 963.

Pisello, A.L., Santamouris, M., Cotana, F., 2013. Active cool roof effect: impact of cool roofs on cooling system efficiency. Advances in Building Energy Research 7 (2), 209–221.

Rahmani, F., Robinson, M.A., Barzegaran, 2021. Cool roof coating impact on roof-mounted photovoltaic solar modules at texas green power microgrid. International Journal of Electrical Power & Energy Systems 130, 1–13.

Sailor, D.J., 1995. Simulated urban climate response to modifications in surface albedo and vegetative cover. Journal of Applied Meteorology and Climatology 34 (7), 1694–1704.

Sailor, D.J., Anand, J., King, R.R., 2021. Photovoltaics in the built environment: A critical review. Energy and Buildings 253, 111479.

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., Martilli, A., 2016. Citywide Impacts of Cool Roof and Rooftop Solar Photovoltaic Deployment on Near-Surface Air Temperature and Cooling Energy Demand. Boundary-Layer Meteorology 161 (1), 203–221.

Santamouris, M., 2019. facing the problem of overheating in Australian cities. Architecture Australia 108 (5), 54–56.

Santamouris, M., 2020. Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. Energy and Buildings 207, 109482.

Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R., Prasad, D., Synnefa, A., 2017a. Passive and active cooling for the outdoor built environment–Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. Solar Energy 154, 14–33.

Santamouris, M., Haddad, S., Fiorito, F., Osmond, P., Ding, L., Prasad, D., Zhai, X., Wang, R., 2017b. Urban heat island and overheating characteristics in Sydney, Australia. An analysis of multiyear measurements. Sustainability 9 (5), 712.

Santamouris, M., M.Papadopoulos, A., Paolini, R., Khan, A., Bartesaghi Koc, C., Haddad, S., Garshasbi, S., Arasteh, S., Feng, J., 2021. Study on the Cool Roofs Mitigation Potential in Australia. University of New South Walse.

Santamouris, M., Synnefa, A., Karlessi, T., 2011. Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Solar Energy 85 (12), 3085–3102.

Scherba, A., Sailor, D.J., Rosenstiel, T.N., Wamser, C.C., 2011. Modeling impacts of roof reflectivity, integrated photovoltaic panels and green roof systems on sensible heat flux into the urban environment. Building and Environment 46 (12), 2542–2551.

Senthilraja, S., Gangadevi, R., Marimuthu, R., Baskaran, M., 2020. Performance evaluation of water and air based PVT solar collector for hydrogen production application. International Journal of Hydrogen Energy 45 (13), 7498–7507.

Simpson, JR, McPherson, E.G., 1997. The effects of roof albedo modification on cooling loads of scale model residences in Tucson, Arizona. Energy and Buildings 25 (2), 127–137.

Spitalny L, Unger D, Maasmann J, Schwerdt P, Van Reeth B, Thiemann A, Myrzik JM (Ed.), 2013. Evaluation of Renewable Energy Technologies in a net Zero Energy Office Building in Germany, 2172-038.

Synnefa, A., Santamouris, M., Akbari, H., 2007. Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings 39 (11), 1167–1174.

Synnefa, A., Santamouris, M., Livada, I., 2006. A study of the thermal performance of reflective coatings for the urban environment. Solar Energy 80 (8), 968–981.

Taha, H., 2013. The potential for air-temperature impact from large-scale deployment of solar photovoltaic arrays in urban areas. Solar Energy 91, 358–367.

Vahmani, P., Sun, F., Hall, A., Ban-Weiss, G., 2016. Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. Environmental Research Letters 11 (12), 124027.

Wang, Y., Tian, W., Ren, J., Zhu, L., Wang, Q., 2006a. Influence of a building's integrated-photovoltaics on heating and cooling loads. Applied Energy 83 (9), 989–1003.

Wang, Y., Tian, W., Zhu, L., Ren, J., Liu, Y., Zhang, J., Yuan, B., 2006b. Interactions between building integrated photovoltaics and microclimate in urban environments. 0199-6231.

Yozwiak, M., Loxsom, F., 2010. Passive cooling of roof-mounted photovoltaic modules. American Solar Energy Society National Solar Confernce.

Zinzi, M., Agnoli, S., 2012. Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. Energy and Buildings 55, 66–76.

Zinzi, M., Fasano, G., 2009. Properties and performance of advanced reflective paints to reduce the cooling loads in buildings and mitigate the heat island effect in urban areas. International Journal of Sustainable Energy 28 (1-3), 123–139.

Zonato, A., Martilli, A., Gutierrez, E., Chen, F., He, C., Barlage, M., Zardi, D., Giovannini, L., 2021. Exploring the effects of rooftop mitigation strategies on urban temperatures and energy consumption. Journal of Geophysical Research: Atmospheres 126 (21), e2021JD035002.

3. Cool Roof Market Potential

3.1 Introduction

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 through decreasing air conditioning needs, and battle urban heat islands. Given these benefits of a cool roof, people still want to know; "How much does a cool roof installation cost?".

Cool roofs, either retrofit or full roof replacement, do not necessarily cost more than non-cool roofs, particularly if retrofitting old roofs. Price will vary wildly, depending on the material used and the design of your home. This report is primarily intended to roughly estimate the installation cost of cool roofs in Australian states and then estimate the related job creation in order to encourage the development of policies, programs, and markets to deliver cool roofs across Australia.

3.2 Total roof area in Australia

The total roof area in Australia for 2015, 2016, and 2020 was calculated based on the data from the National Exposure Information System[3] (NEXIS) available in AURIN[4]. The result for total roof area in Australia was also validated by repeating calculations based on Microsoft's Australia Building Footprints available via the following Github site[5]: https://github.com/microsoft/AustraliaBuildingFootprints. The total roof area difference between the two databases was less than 1.28 Km^2 or around 0.4% (NEXIS: 2,744 and Github: 2745). **Table 7** shows the estimated results from NEXIS for all 8 states of Australia in 2020.

Table 7 Estimated total roof area in Australia (2020)

Database	**NEXIS - AURIN**	
State	m^2	km^2
NSW	769,182,508	769
VIC	722,213,222	722
QLD	591,826,069	592
SA	234,969,514	235
WA	300,087,454	300
TAS	72,225,282	72
NT	23,771,724	24
ACT	29,860,844	30
Total	2,744,136,617	2,744

[3] The National Exposure Information System (NEXIS) is a Geoscience Australia capability designed to provide comprehensive and nationally consistent exposure information to enable users to understand the elements at risk. Exposure information is produced by sourcing the best publicly available information, statistics, spatial and survey data about buildings, demographics, community infrastructure and agricultural commodities.

[4] AURIN is a collaborative national network of leading researchers and data providers across the academic, government, and private sectors. We provide a one-stop online workbench with access to thousands of multidisciplinary datasets, from over 100 different data sources.

[5] This dataset is freely available for download and use under the Open Data Commons Open Database License (ODbL). The footprints were generated from Bing maps satellite imagery (Maxar technologies). The dataset contains 11'334,866 computer generated building footprints in shapefile format. The AI-assisted building extraction was performed by Microsoft in two stages: 1) Semantic Segmentation – Recognizing building pixels on the aerial image using DNNs. 2) Polygonization – Converting building pixel blobs into polygons With a precision of 98.59%.

3.3 Annual roof installation in Australia from 2015 to 2020

According to the estimated data from NEXIS, around 67 km^2 of new roofs were installed from 2015 to 2016 (see **Table 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 **Table 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.

Table 8 New roof installation, 2015-2016

State	Residential buildings (m^2)	Industrial buildings (m^2)	Commercial buildings (m^2)	Total (m^2)	Total (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
QLD	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
NT	169,206	389,105	95,072	653,383	1
ACT	754,813	26,616	830,280	1,611,708	2
total	36,875,950	12,142,125	18,326,059	67,344,134	67

Table 9 Total roof installation from 2016 to 2020

State	Residential buildings (m^2)	Industrial buildings (m^2)	Commercial buildings (m^2)	Total (m^2)	Total (km^2)
NSW	87,306,886	122,272	739,295	88,168,453	88
VIC	68,712,861	4,225,222	-1,532,090	71,405,993	71
QLD	58,488,792	-8,257	2,786,503	61,267,038	61
SA	16,786,074	2,842,537	18,626,978	38,255,588	38
WA	28,240,940	4,346,580	4,523,875	37,111,395	37
TAS	948,874	-1,864,017	8,667,690	7,752,547	8
NT	2,485,097	1,078,764	1,117,225	4,681,086	5
ACT	1,378,619	42,234	-75,408	1,345,445	1
Total	264,348,143	10,785,334	34,854,068	309,987,545	310

3.4 Annual cool roof installation cost in Australia

The standard cost of the cool roof material in Australian dollars (AUD) per square meter has been collected in *Volume 1 (International Progress, Technology, Market, and Legislative Frame)* for 14 products. The report results showed that the average cost of the cool roof material per square meter is \$13 AUD/m^2. The highest price collected is \$32.5 AUD/m^2, while the lowest one is \$2.5 AUD/m^2.

This section of the report estimates the minimum and maximum cost of cool roof implications for different building types in all 8 Australian states. This estimation was applied for total roof area in 2020 and annual new roof area between 2015 and 2016.

Table 10 and **Table 11** show that the estimated minimum and maximum cost of cool roof implication for total roofs in Australia in 2020 is AUD$6.9b (USD$4.9b) and AUD$89.2b (USD$64.2b) respectively, which 84% could allocate to residential buildings, 9% to commercial buildings and 7% to industrial buildings.

Table 12 and **Table 13** show the minimum and maximum annual economic potential of cool roof application for new roofs in Australia between 2015 and 2016. The minimum estimated cost is AUD$168m (USD$121m) and the maximum is AUD$2.2b (USD$1.6b), which 55% for residential buildings, 27% for commercial buildings and 18% for industrial buildings.

Table 10 Minimum and maximum cost for the total roof in 2020 (AUD)

State	Min cost for Residential buildings (AUD)	Max cost for Residential buildings (AUD)	Min cost for Industrial buildings (AUD)	Max cost for Industrial buildings (AUD)	Min cost for Commercial buildings (AUD)	Max cost for Commercial buildings (AUD)	Min (Total AUD)	Max (Total AUD)
NSW	1.6b	21.3b	142m	1.8b	139m	1.8b	1.9b	25.0b
VIC	1.5b	19.8b	139m	1.8b	142m	1.8b	1.8b	23.5b
QLD	1.3b	16.6b	92m	1.2b	113m	1.5b	1.5b	19.2b
SA	468m	6.1b	22m	280m	98m	1.3b	587m	7.6b
WA	626m	8.1b	70m	909m	54m	705m	750m	9.8b
TAS	130m	1.7b	9m	113m	42m	547m	181m	2.3b
NT	45m	587m	8m	108m	6m	77m	59m	773m
ACT	66m	864m	1m	14m	7m	92m	75m	970m
Total	**5.8b**	**75.1b**	**483m**	**6.3b**	**602m**	**7.8b**	**6.9b**	**89.2b**

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

State	Min cost for Residential buildings (USD)	Max cost for Residential buildings (USD)	Min cost for Industrial buildings (USD)	Max cost for Industrial buildings (USD)	Min cost for Commercial buildings (USD)	Max cost for Commercial buildings (USD)	Min (Total)	Max (Total)
NSW	1.2b	15.4b	102m	1.3b	100m	1.3b	1.4b	18.0b
VIC	1.1b	14.3b	100m	1.3b	102m	1.3b	1.3b	16.9b
QLD	917m	11.9b	67m	866m	82m	1.1b	1.1b	13.8b
SA	337m	4.4b	15m	201m	70m	916m	423m	5.5b
WA	451m	5.9b	50m	654m	39m	508m	540m	7.0b
TAS	93m	1.2b	6m	82m	30m	394m	130m	1.7b
NT	33m	423m	6m	78m	4m	56m	43m	556m
ACT	48m	622m	1m	10m	5m	66m	54m	699m
Total	**4.2b**	**54.1b**	**348m**	**4.5b**	**433m**	**5.6b**	**4.9b**	**64.2b**

[6] AUD conversion @0.72 per USD at the time of writing

Table 12 Annual Minimum and Maximum cost for building cool roof in AUD (2015-2016)

State	Min cost	Max cost
NSW	$52m	$670m
VIC	$57m	$736m
QLD	$31m	$397m
SA	$8m	$110m
WA	$14m	$347m
TAS	$2m	$21m
NT	$2m	$21m
ACT	$4m	$52m
Total	**$168m**	**$2.2b**

Table 13 Annual Minimum and Maximum cost for building cool roof in USD (2015-2016)

State	Min cost	Max cost
NSW	$37m	$482m
VIC	$41m	$530m
QLD	$22m	$286m
SA	$6m	$79m
WA	$10m	$131m
TAS	$1m	$15m
NT	$1m	$15m
ACT	$3m	$38m
Total	**$121m**	**$1.6b**

3.5 Economic potential of cool roof application

In this section, the potential number of direct jobs, indirect jobs and induced jobs creation by cool roof application in Australia were calculated by using the following consideration:

- Number of direct jobs considering 7 jobs per million of USD
- Number of indirect jobs considering 4.9 Jobs per million of USD
- Number of induced jobs considering 11.8 Jobs per million of USD

Table 14, **Table 16** and **Table 18** present the potential number of job creation via cool roof application for total roof area in 2020. In total, 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.

Table 15, **Table 17** and **Table 19** present the potential number of direct jobs creation by applying cool roof for new roof area between 2015 and 2016. The results show that application of cool roof can provide in average 5,940 direct jobs, 173 indirect jobs and 10,013 induced jobs.

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

State	Min number of direct job (Residential buildings)	Max number of direct job (Residential buildings)	Min number of direct job (Industrial buildings)	Max number of direct job (Industrial buildings)	Min number of direct job (Commercial buildings)	Max number of direct job (Commercial buildings)	Total (Min direct Job creation)	Total (Max direct Job creation)
NSW	8,273	107,553	716	9,310	702	9,129	9,692	125,992
VIC	7,682	99,865	702	9,128	716	9,305	9,100	118,299
QLD	6,419	83,453	466	6,059	571	7,429	7,457	96,941
SA	2,359	30,668	108	1,410	493	6,410	2,961	38,488
WA	3,155	41,019	352	4,580	273	3,555	3,781	49,154
TAS	654	8,503	44	572	212	2,756	910	11,831
NT	228	2,959	42	546	30	389	300	3,894
ACT	335	4,354	6	73	36	464	376	4,891
Total	**29,106**	**378,374**	**2,437**	**31,678**	**3,034**	**39,437**	**34,576**	**449,490**

Table 15 Direct job creation between 2015 and 2016 (for new roof area)

state	Min direct Job creation	Max direct Job creation	Average direct Job creation
NSW	260	3,377	1,818
VIC	285	3,708	1,996
QLD	154	2,000	1,077
SA	43	555	299
WA	70	916	493
TAS	8	105	56
NT	8	107	58
ACT	20	264	142
Total	**849**	**11,031**	**5,940**

Table 16 Indirect job creation in 2020 (for total roof area)

State	Min number of indirect job (Residential buildings)	Max number of indirect job (Residential buildings)	Min number of indirect job (Industrial buildings)	Max number of indirect job (Industrial buildings)	Min number of indirect job (Commercial buildings)	Max number of indirect job (Commercial buildings)	Total (Min indirect job creation)	Total (Max indirect job creation)
NSW	241	3,136	21	271	20	266	283	3,673
VIC	224	2,912	20	266	21	271	265	3,449
QLD	187	2,433	14	177	17	217	217	2,826
SA	69	894	3	41	14	187	86	1,122
WA	92	1,196	10	134	8	104	110	1,433
TAS	19	248	1	17	6	80	27	345
NT	7	86	1	16	1	11	9	114
ACT	10	127	0	2	1	14	11	143
Total	**849**	**11,031**	**71**	**924**	**88**	**1,150**	**1,008**	**13,105**

Table 17 Indirect job creation between 2015 and 2016 (for new roof area)

state	Min indirect job creation	Max indirect job creation	Average indirect job creation
NSW	8	98	53
VIC	8	108	58
QLD	4	58	31
SA	1	16	9
WA	2	27	14
TAS	0	3	2
NT	0	3	2
ACT	1	8	4
Total	**25**	**322**	**173**

Table 18 Induced job creation in 2020 (for total roof area)

State	Min number of induced job (Residential buildings)	Max number of induced job (Residential buildings)	Min number of induced job (Industrial buildings)	Max number of induced job (Industrial buildings)	Min number of induced job (Commercial buildings)	Max number of induced job (Commercial buildings)	Total (Min induced job creation)	Total (Max induced job creation)
NSW	13,946	181,304	1,207	15,694	1,184	15,388	16,337	212,387
VIC	12,950	168,344	1,184	15,388	1,207	15,685	15,340	199,418
QLD	10,821	140,678	786	10,214	963	12,524	12,570	163,415
SA	3,977	51,697	183	2,377	831	10,806	4,991	64,880
WA	5,319	69,146	594	7,721	461	5,993	6,374	82,860
TAS	1,103	14,333	74	964	357	4,646	1,534	19,943
NT	384	4,988	71	920	50	656	505	6,564
ACT	565	7,340	9	122	60	783	634	8,245
Total	49,064	637,831	4,108	53,400	5,114	66,480	58,285	757,711

Table 19 Indirect job creation between 2015 and 2016 (for new roof area)

state	Min induced job creation	Max induced job creation	Average induced job creation
NSW	438	5,692	3,065
VIC	481	6,250	3,365
QLD	259	3,371	1,815
SA	72	936	504
WA	119	1,545	832
TAS	14	176	95
NT	14	180	97
ACT	34	445	240
Total	**1,430**	**18,595**	**10,013**

3.6 Conclusion

- The total minimum and maximum potential cost of cool roof installation for **all roofs** 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 **new roofs** 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. Proposals for 2025 revision of the Building Code of Australia and testing

4.1 Introduction

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:

- 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.
- Recommendations for steps needed to advance usage in Australia. E.g.:
  - Standards
  - Code stringency
  - Guidance, knowledge sharing or demonstrations
  - Incentives
  - Premiums for these new products compared to other roofing products
- 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.
- 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 Analysis of the current regulatory framework

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 (Australian Building Codes Board, 2019). The prescription does not apply to apartment buildings. Verbatim from J1.1 Application of Part:

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) **(Figure 13)**. In some situations, the prescription is modified in South Australia **(Figure 14)**, indicating a maximum solar absorbance of 0.40 **(Figure 14)**, as given in the State annexe.

J1.3 Roof and ceiling construction

(a) A roof or ceiling must achieve a *Total R-Value* greater than or equal to—

  (i) in *climate zones* 1, 2, 3, 4 and 5, R3.7 for a downward direction of heat flow; and

  (ii) in *climate zone* 6, R3.2 for a downward direction of heat flow; and

  (iii) in *climate zone* 7, R3.7 for an upward direction of heat flow; and

  (iv) in *climate zone* 8, R4.8 for an upward direction of heat flow.

(b) In *climate zones* 1, 2, 3, 4, 5, 6 and 7, the solar absorptance of the upper surface of a roof must be not more than 0.45.

SA J1.3(c)

Figure 13 Deemed to Satisfy Provision on the solar absorbance of roofs in the National Construction Code (Vol 1).

SA Part J1 Building fabric

After J1.3(b) insert SA J1.3(c) as follows:

SA J1.3 Roof and ceiling construction

(c) If a Class 5, 6, 7, 8 or 9 building, or part of a building—

  (i) is constructed in *climate zone* 4 or 5; and

  (ii) has a roof pitch of not more than 5 degrees; and

  (iii) has a *conditioned space*,

the roofing material must have an upper surface solar absorptance value of not more than 0.4.

Figure 14 South Australia Annexe to the NCC Vol 1. Deemed to Satisfy Provision on the solar absorbance of roofs in the National Construction Code.

Aspects currently not addressed:

Several elements are not covered in the 2019 and 2022 editions of the National Construction Code and would therefore to be addressed:

- There is no prescription on the maximum solar absorbance of residential buildings, which constitute the majority of rooftops, due to the urban sprawl in most Australian cities.

- 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 Proposals in preparation for NCC2025 revision

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 an “equivalent SRI” for green roofing with low solar reflectance and low surface temperature due to 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 maximum solar absorbance) should not be simple Deemed to Satisfy Provisions. In fact, DtS Provisions can be avoided by implementing a Performance Solution, which on paper would still have the same result in terms of energy consumption (i.e., the heat transfer through a roof with 300 mm of thermal insulation is negligible, regardless of the solar reflectance and thermal emittance of the outmost layer). However, the solar absorptive roof would increase the turbulent sensible heat flux into the urban atmosphere, thus contributing to worsening urban overheating and indirectly increasing the cooling energy consumption of all buildings. If a building of limited dimensions is the only one in the area with high solar absorbance, its contribution to urban overheating is negligible. If it is a large scale building (e.g., a shopping mall) or all buildings in the area have a low albedo, this increases urban temperatures. Therefore, the current verification methods by simulations do not consider this aspect. Verification with NABERS considers all aspects, instead, as it is based on metered data. Therefore, this loophole should be addressed. Further, an urban overheating section or performance requirement would allow the introduction of performance-based requirements that would apply to any roofing type, covering also green roofing or more advanced technologies. In fact, once the principle of the SRI is used, it is possible to define an “Equivalent SRI” or SRI_{eq} based on the measured surface temperature of alternative solutions being a green roof, daytime radiative coolers (i.e., the future generation of cool roofs), or a future generation of photovoltaic modules with high conversion efficiencies and low overheating. This would remove the need for continuous revisions and patches in the structure of the performance requirements.

Proposal 3*. *Limits to SRI for all buildings, including residential. The thresholds on the SRI should be applied to all building classes, from 1 to 10 (yes, including carports). Any building with a roof should be subject to the limits. In fact, residential buildings have the largest cumulative roof area in Australian cities (2,744 km^2).

Proposal 4. Limits apply to retrofits. In case of reroofing or substantial roofing maintenance, the new limits apply. Exemptions for architectural heritage buildings should be included in the National Construction Code.

Proposal 5. Limits cannot be set back by Local Govemenents. Councils cannot reduce SRI requirements for new developments. Limits for architectural heritage can be modified. Near infrared reflective options having the same colour as heritage materials should be considered.

Proposal 6. Different SRI for pitched and sloped roofs. There should be a separate indication for the SRI limits for pitched and low-sloped (or flat) roofs, as it is commonly done in international codes.

Proposal 7. Explicit indication of standard test and calculation methods. The standard test methods and calculation procedures should be referenced in line and not simply in schedule 4, where they are lost. The commonly adopted standard test methods are described below by category.

A complete overview of methods is provided in ANSI/CRRC S100. An Australian version should be developed by the future (to be established) Australian Cool Roofing Council

- ANSI/CRRC S100 (2021) “Standard Test Methods for Determining Radiative Properties of Materials” (Cool Roofing Rating Council, 2021).

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

- ASTM E1980 “Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low- Sloped Opaque Surfaces” (ASTM International, 2011).

Solar Reflectance

There are three main measurement methods to characterise the solar reflectance of a product: with a spectrophotometer in the laboratory (on small and flat samples), with a portable reflectometer in the laboratory or in the field on flat portions of roofing, and with an albedometer in the field on large samples (typically 4 m x 4 m or 1 m x 1 m with a modified non-standard method). A discussion of the different test methods and solar spectra is provided by Levinson et al. (2010a, 2010b).

With a UV-Vis-NIR spectrophotometer, which can be done only in the laboratory, typically on small flat samples of 100 mm x 100 mm, with a measured area of approximately 1 cm^2 **(Figure 15)**. A collimated beam incident on the sample’s surface with an angle of 6-10° (depending on the instrument model) is reflected and scattered radiation measured by sensors at the bottom of the integrating sphere. This method is not adequate to measure non-flat or patched products (i.e., with variegated solar reflectance over their surface). To characterise moderately variegated samples (e.g., asphalt shings or concrete samples that exhibit some surface roughness), multiple measurements can be performed.

The main advantage of this test method is that it provides spectral information, which is essential in research and product development to enhance the performance, and to investigate the degradation of materials. Extremely soiled samples can potentially damage the integrating sphere, and for this porpose there are integrating spheres with horizontal sampling. A single measurement scan is typically completed in approximately 2-3 minutes (depending on the scan settings).

There are three main test methods that provide slightly different results due to the weighting function (i.e., reference solar spectrum) and averaging procedure used to calculate the solar reflectance out of the spectral reflectance values.

- ASTM E903-12 “Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres” (ASTM International, 2012).
- ISO 9050 “Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors”. (ISO, 2003)
- EN 410 “Glass in building - Determination of luminous and solar characteristics of glazing”.

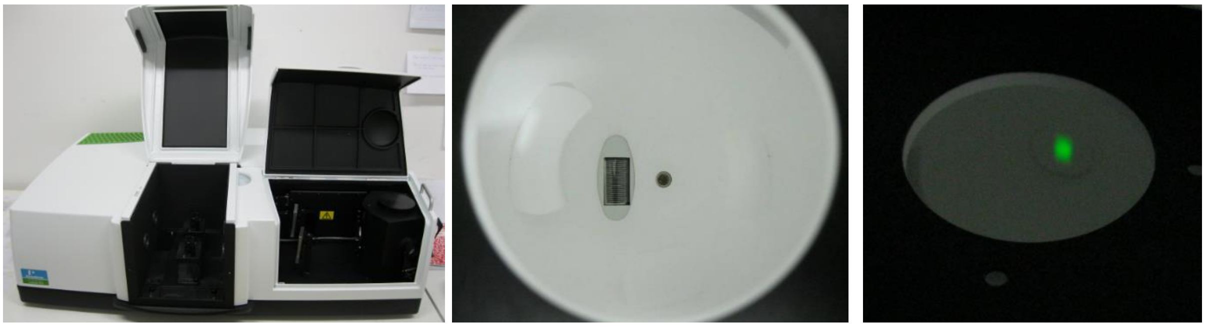


Figure 15 Spectrophotometer with an integrating sphere, with a detail of the photomultiplier and PMT detector (in this case) at the bottom of the sphere and then the measurement beam at the reflectance port.

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

- ASTM C1549-16 “Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer” (ASTM International, 2009)

Measurements with a portable reflectometer can be conducted on soiled samples by placing the instrument vertically over the dirty sample, without risk of damaging the integrating sphere within the instrument **(Figure 16)**. The instrument is portable, if equipped with a battery and can be used in the field. Samples are diffusely illuminated, measuring at a port of 1 inch in diameter. Only the solar reflectance is measured, according to different standards and solar irradiance distributions (for different air masses). These can be selected by the user.

Figure 16 A portable reflectometer by Devices & Services, Texas, US. The entire apparatus and the view from the top are shown.

For measurements with an albedometer (or two back to back pyranometers), there is only an ASTM method:

- ASTM E 1918 “Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field” (ASTM, 2016)

An albedometer is typically made of two back-to-back pyranometers measuring solar radiation from 280 to 2800 nm **(Figure 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).

Figure 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 **(Figure 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 C1371-15 “Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers” (ASTM International, 2015)
- EN 15976: 2011 “Flexible sheets for waterproofing - Determination of emissivity” (CEN, 2011)
- EN 12898 “Glass in building. Determination of the emissivity” (CEN, 2001)
- ASTM E408-13 (2019) “Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques”

Emissometers such as that by Devices & Services (implementing the method in ASTM C1371) require samples with minimum diameter of 5.7 cm, while the TIR by Inglass (implementing the method in EN 15976) require samples of minimum 10 cm. This is to be taken into consideration when producing samples for laboratory or natural exposure, which then have to be measured.

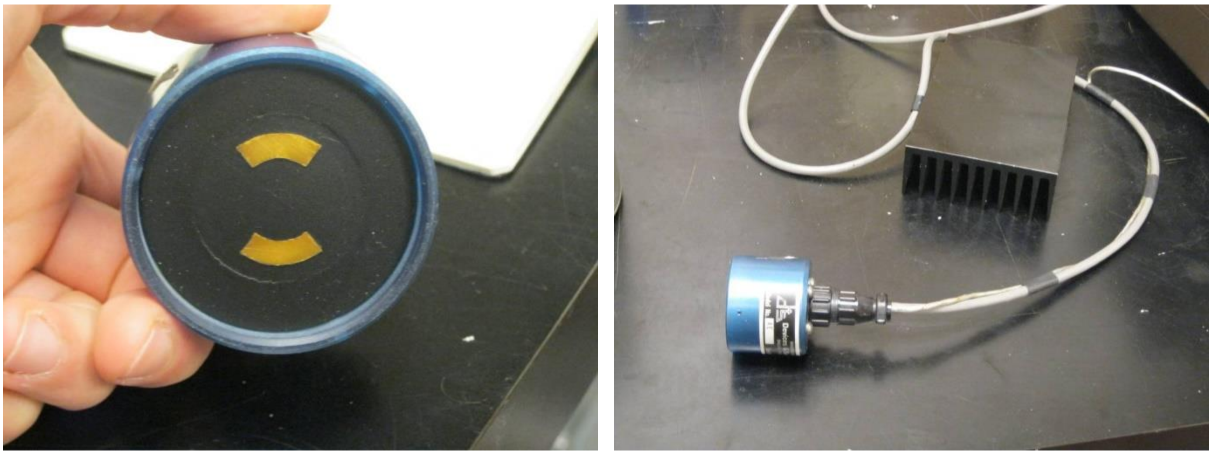


Figure 18 A portable emissometer. The image shows the sensing elements and the whole apparatus with the heat sink over which the samples are measured.

Natural exposure and laboratory exposure procedures

The natural exposure procedures are quite general and need local adaptation.

- ISO 2810 “Paints and varnishes – Natural weathering of coatings - Exposure and assessment” (ISO, 2004)
- ASTM G7-05 “Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials” (ASTM International, 2005)

- The standards for natural exposure are mostly guidelines, with further details provided in ANSI/CRRC S100 (Cool Roofing Rating Council, 2021). Also, a critical analysis of lessons learnt from natural exposure programs is presented in (Paolini et al., 2020).

There is only one standard for laboratory soiling exposure used by the CRRC to achieve interim SRI values, to be later replaced by data from the natural exposure, and it is ASTM D7897. This standard has been developed for the US only, and there is only one non-standard version that demonstrates the possibility of tuning the method for the application out of the United States (Paolini et al., 2020). The reproducibility and repeatability of the protocol have been assessed in an interlaboratory comparison (Sleiman et al., 2015).

- ASTM D 7897-18. Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance (ASTM International, 2018)

Proposal 8. Standard test methods and calculation procedures part of the NCC. Whenever possible, the NCC should include the formulas (which are not protected by copyright) and measurement principles and descriptions, reducing the amount of information behind a paywall. This would be similar to what was done for the daylight factor, for instance.

Proposal 9. Interim unaged and aged values for SRI limits. There should be a requirement on the aged performance of roofing products, upon testing. However, this can be set once Australia's accreditation and testing framework is implemented. Therefore, there would be the need for a staged approach with interim values. This would provide the industry with ample notice to adapt and implement all changes to achieve the targets. The thresholds indicated below apply to climate zones from 1 to 7.

Stage 1. NCC 2025 – Minimum unaged values

Roof	SRI	Solar Reflectance	Thermal emittance
Flat or low-sloped (≤ 2:12)	75	0.65	0.75
Pitched (> 2:12)	18	0.25	0.75

Stage 2. NCC2028 (or NCC2031) – Minimum on aged values (after 3 years of natural exposure)

Roof	SRI	Solar Reflectance	Thermal emittance
Flat or low-sloped (≤ 2:12)	57	0.53	0.75
Pitched (> 2:12)	18	0.25	0.75

Stage 3. NCC2031 (or NCC2034) – Minimum aged values (after 3 years of natural exposure)

Roof	SRI	Solar Reflectance	Thermal emittance
Flat or low-sloped (≤ 2:12)	76	0.65	0.80
Pitched (> 2:12)	21	0.25	0.80

All products are to be rated by the future Australian Cool Roofing Council (to be established). All products can be rated even if they have lower SRI than the defined thresholds, but compliance can be met only for products above the thresholds previously discussed.

Exceptions to the SRI thresholds are to be considered for anti-slip portions on rooftops (e.g., walkways) or less than 10% of the roof surface.

Roof sheeting over mechanical rooms and ducting is advised whenever it improves the performance of the HVAC system. After extensive consultation with the industry, a mandate to cover mechanical rooms with roof sheeting and coat HVAC ducting with high SRI materilas (which would reduce HVAC overheating) is to be considered after NCC2028.

Aged values must be used in building energy simulations (e.g., for NatHERS or any simulation performed as verification with the reference building).

Rationale in the thresholds definition and commentary. A staged approach with progressively more stringent requirements has traditionally been implemented in other areas of Section J of the NCC (e.g., minimum NatHERS and NABERS star rating) and overseas. Also, a staged approach with unaged and then aged thresholds has been implemented in the United States with the Cool Roofing Rating Council (Cool Roofing Rating Council, 2018b).

The definition of solar reflectance and thermal emittance thresholds in the building code needs to be evidence-based. Cool roofs heating penalties are largely lower than the cooling energy savings (due to direct and indirect effects) in Australian Capital Cities (see the relevant reports in this project). Therefore, reducing cooling energy 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

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

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 reduction. 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 manufacturer with recommended solutions assessed experimentally, after inspection on existing buildings, and by means of numerical heat and moisture transport simulations as indicated in FV6 (ASHRAE, 2009; CEN, 2007). ASHRAE 160 and EN 15026 should be referred to explicitly as standard documents defining the requirements for numerical simulation models for combined heat and moisture transfer and storage in porous media. Extensive consultation with the industry is advised.

4.4 Incentives

The definition of the exact value for the incentives should come after a cost-benefit analysis considering all direct and indirect costs, modelling the reduced environmental pollution and avoided capital investment to reduce the peak power demand for cooling, and considering the benefits to the economy.

Cool roofs have been promoted with a wide range of incentives in the United States and Europe. In the United States, specific incentives focused on promoting cool roofs provide rebates of 0.20 USD per ft^2 of cool roof (meeting the thresholds) in Pasadena, CA, or incentives from the energy utilities, because of the peak load reduction. In the EU, cool roofs are considered energy efficiency interventions and receive general incentives. In Italy, for instance, such incentives allowed the discount of 50% of the upfront installation cost from the gross income (spread over 10 years), thus leading to tax savings. States and Territories should define the most appropriate form to incentivise renovations. Therefore, here we propose two categories of incentives in the form of tax rebates:

- For reroofing of existing buildings
- For new constructions where the minimum SRI value is exceeded.
    - A first level of incentives could be given when the minimum SRI is exceeded by 20%;
    - A second level of incentives only for low-sloped roofs with aged SRI exceeding 100, thus supporting super-cool roofs that retain high albedo over time.

Another type of incentive that has been adopted overseas is the financing of energy efficiency interventions (for either new construction or refurbishment) at a discounted rate set by the central bank (in this case, the RBA), even with a cap set by the regulator on rates provided by lenders. The rationale behind this incentive is that energy efficiency investments have a sure return (i.e., energy consumption decreases) with the only uncertainty associated with the payback time (e.g., sequence of hot or cold years). Therefore, energy efficiency is a very 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, often over several years.
- Discounted financing rates.

Incentives have been implemented overseas at the Union/Federation level (e.g., EU/USA), state or regional level, and municipality level (Part 1 of this project). Here, we provide the following high-level recommendations on the features that an incentives scheme should have:

- *Easy to understand and use*. Measures such as tax deductions are easy to understand for the consumer, who can calculate the direct advantage in their situation. Incentives that are easy to understand and do not require assistance from an accountant intervene in the early decision-making stages. If direct benefits are not clear
- *Modular*. If applicable and appropriate, a modular structure allows the cumulation of benefits at national, state/territory, and council levels. For instance, the Commonwealth contributes for X%, then a State/Territory with a particularly hot climate might decide to contribute with a further Y%, and a council might have additional indirect benefits leading to a contribution of Z% of the investment. This way, the sum of the contributions would be T% = X+Y+Z, retaining the ease of use and understanding for the consumer. If, instead, a state decides to provide additional benefits in terms of rebates of the stamp duty and then the local government reducing the council tax, the benefits would be evident to the investor but not immediately clear, opening many tax scenarios.
- *Include an immediate contribution*. The incentives should work towards overcoming the initial investment (e.g., by providing support towards a deposit for a loan for energy efficiency interventions). This measure would overcome the main hurdles that block refurbishment interventions in energy efficiency. An example of an immediate contribution might be a voucher contributing to the initial costs of an energy assessment of the property (e.g., limited to residential buildings) and assistance in the process.

4.5 Proposal for a testing and accreditation infrastructure in Australia

Once the costs and benefits are clear, and a system of incentives has been established, the widespread application of cool roofs cannot begin without a testing and accreditation infrastructure. In this section, we outline a proposal for a roadmap towards establishing such testing and accreditation infrastructure, which cannot be implemented without strong industry participation.

Rationale. A testing and accreditation infrastructure is an essential tool to achieve several goals:

- *Protect and support the consumer*. A recognisable and transparent national accreditation infrastructure builds confidence in the consumers' markets and assists consumers and project & construction managers in selecting the most appropriate product with the certainty of delivered performance.

- *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 certificate of Accreditation
    - A current certificate "issued by a certification body stating that the properties and performance of a material, product, form of construction or design fulfil specific requirements of the BCA".
    - A report issued by an Accredited Testing Laboratory
    - A certificate or report from a professional engineer or another appropriately qualified person
    - Another form of documentary evidence, such as but not limited to a Product Technical Statement
- *Be unequivocal, repeatable, and support-decision making and dispute resolution*. Have a clear reference for compliance checks in dispute resolution, especially for public procurement. This point is relevant when an invitation to tender includes a technical-economical assessment of bids that are either accepted beyond a threshold or ranked as a function of the SRI or solar reflectance. In such cases, product certificates issued by different laboratories might provide different values if a consensus on the calculation procedure is not established, and a comparison might prove difficult. For instance, the same product tested according to different standards (e.g., ISO 9050 or ASTM E903) might have different solar reflectance. Also, unaccredited laboratories that do not perform instruments calibration, maintenance, and without traceability can deliver results that are not repeatable or reproducible (for repeatability and reproducibility, please refer to ASTM E603).

Testing and accreditation infrastructures have been established overseas in various fashions, with different results and perceptions by the industry. Some testing infrastructures, for instance, have been perceived as a burden by the industry, without a clear benefit beyond a certificate allowing the commercialisation of goods.

Here, we provide high-level recommendations concerning the pillars that should inspire the testing and accreditation infrastructure.

Pillar 1 – Industry-led association governing the testing and accreditation infrastructure. With voluntary participation, an industry-led Australian Cool Roofing Council (ACRC) is established. Here, we propose the interim name of the Australian Cool Roofing Council, in analogy with the US Cool Roofing Rating Council and European Cool Roofing Council. The name could be revised, for instance, to include all cool materials (e.g., Australian Cool Materials Council or similar). The ACRC is participated by Government, Universities, Research Institutions, and accredited laboratories, with leadership expressed by the industry. The industry leadership 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 laboratories. 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 of the laboratory's test results shall be conducted following the same criteria that were used to 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 tested and commercialised products have the same performance. This recommendation is in line with the FPC 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 advised. Regardless of choice, only one air mass should be selected, as computing the solar reflectance for different air masses for the same product (not spectrally flat) would lead to slightly different results (Levinson et al., 2010a).

For measurements of solar reflectance, three test methods are advised:

- ASTM E903 with AM1GH for measurements with a spectrophotometer
- ASTM C1549 for measurements using a portable solar reflectometer, selecting the output for AM1GH. This method can be used for inspections (only a small flat area is measured)
- ASTM E1918 for measurements using an albedometer in the field. This method should be preferred for non-flat surfaces such as roofs made with concrete or clay tiles, or metal sheeting, as it best measures the reflectance of a rough (i.e., non-flat) surface, as documented in the literature (Akbari, Levinson, et al., 2008; Berdahl et al., 2008; Levinson et al., 2010b). Also, this method can be used for inspections.

For measurements of thermal emittance, three test methods are advised:

- ASTM C1371 using a portable emissometer (calorimetric method).
- EN 15976 and EN 16012 using a radiometric emissometer (Kononogova et al., 2019).
- EN 12898 using an FTIR spectrometer.

Pillar 6 – Performance over Time. The solar reflectance and thermal emittance (and resultantly computed SRI) should be assessed before and after natural exposure at representative sites. This pillar should include three parts:

- 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 climate zone (e.g., one in Perth and one in Sydney) would not offer substantially different information. It would be advisable to have one site in a temperate and one in a hot and humid area.
- Polluted areas should not be avoided but included if representative of where the majority of the population lives, while avoiding proximity to specific sources such as a coal-fired power plant, an airport, major construction sites, or bushfire prone areas. Therefore, the sites should be located in relatively developed areas.

- There should be a reasonable compromise between the land cost for the testing farm and the representativity of the exposure conditions. An industrial area in Western Sydney, for instance, may offer an acceptable compromise, while an area far from the main metropolitan areas would not be representative of the conditions to which most of the buildings in climate zones 5 and 6 are exposed.
- The exposure sites must not be recommissioned for a long period, as changing the exposure site would invalidate a campaign and break the historical series and comparison.
- The sites should be equipped with a weather station measuring air temperature, humidity, wind speed and direction, air pressure, and an air quality station measuring at least PM2.5 and PM10. Ozone, NOx, and SOx may be helpful, and direct measurement of black carbon is advised. Further, incoming global radiation on the horizontal plane, infrared radiation from the sky, and total ultraviolet radiation must be measured (Jacques, 2000).
- A batch of reference or control samples of known performance and durability should be re-exposed every year, serving as a term of comparison. This is widely recommended by both ISO and ASTM standards (ASTM International, 2005; ISO, 2004) as in the literature (Paolini et al., 2020). At least one product type (e.g., metal, single-ply membrane, ceramic) should be included in the set of reference samples. The purpose is to assess interannual variability and potentially exclude anomalous years.

The use of rooftops for exposure sites has been previously criticised within other cool roofing councils, mentioning the turbulence around rooftops. However, tautologically, we note that building rooftops are the most representative climate for roofing products. Further, ground-level exposure might be influenced by dust and soiling in the proximity of the surface, which can be not representative of the conditions on a rooftop, even if of a low-rise building. Further, humidity and temperature near the ground are remarkably different from those observed on rooftops (World Meteorological Organization, 2018). Therefore, provided the availability of a suited light-industrial building with a sufficiently large flat roof (without evaporative coolers or chimneys) not subject to decommissioning for a reasonably long period (e.g., 25 years), the option of rooftops should be considered.

The exposure conditions should be representative of the in-use conditions. Therefore, the exposure should take place:

- With a slope between 1% and 2% for products for flat roofing applications
- The typical slope for metal roofing for metal sheeting products
- With an intermediate slope representative of tiled roofing applications for clay and concrete tiles.

Currently, exposure at US sites following ASTM G7 (ASTM International, 2005) occurs with a tilt of 5° and 45°. However, a 5° slope is not representative for flat roofing applications, as tilt greatly influences the UV ageing and soiling of materials (Paolini et al., 2014).

“One slope fits all” is not an approach that supports product development, as it does not reproduce the actual installation and in-use conditions.

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. For instance, manufacturers who have their products rated after a bushfire season would be penalised with respect to manufacturers who completed their rating the year before. With multi-year exposure, this risk is minimised. Also, if an anomalous year is excluded (e.g., exceptional bushfire), the manufacturer would not need to start the exposure campaign from scratch, losing three years.

The first exposure campaign for a product (e.g., starting in 2022) could provide interim values after 3 years, with the final rating completed two years later (i.e., including exposure campaigns started in 2023 and 2024).

Therefore, the final rated solar reflectance and thermal emittance of a product would be the three-site average (e.g., Darwin, Sydney, and Alice Springs) of the multi-year averages for each site (e.g., the average values at the end of exposures started in 2022, 2023, and 2024).

Feedback from practice with annual inspections. Data from inspections of existing buildings should complement the information gathered with natural exposure. Some aspects such as stress-strain cycles or accumulation of soiling due to specific geometrical features of roofing systems cannot be observed with natural exposure of small samples (typically 10 cm x 10 cm). This is also recommended by ISO 15686-2 (Daniotti & Re Cecconi, 2010; ISO, 2012).

At least one measurement per product per year should be performed on-site by an independently accredited tester/inspector, randomly selected by the ACRC for the annual inspection. The use of data measured on-site should be considered not as an alternative but as a verification method. For instance, if a product shows on-site a reflectance that is significantly lower than that observed after natural exposure, an investigation by the ACRC should be automatically triggered, giving 24 months (proposed) to the manufacturer to address the issue. If the outcome of the investigation is that no action has been undertaken to ensure the quality of installation, the product rating can be withdrawn.

The scheme of annual inspections should be designed with the aim of funnelling information to the manufacturers to improve products and quality of installation, and not with a merely punitive purpose.

Rapid rating - Interim testing with laboratory exposure. Before natural exposure is completed and results are available, interim aged results could be achieved

- With early results from the natural exposure (advised), such as 18 months, which for most products provide a value close to the long-term (3-year) reflectance loss (Paolini et al., 2020); or
- With a laboratory exposure practice as described in ASTM D7897 (ASTM International, 2018). This procedure was originally developed to mimic weathering and soiling at the three US sites of the CRRC

(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).

The database, in addition to the manufacturer's contacts and product name, should contain:

- Time zero (unaged) solar reflectance, thermal emittance, and SRI
- Interim values (with rapid rating or early results from natural exposure, indicating the method)
- 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 conditions and validity of the certificate.

4.6 Conclusions

In this section, we first offered an analysis of the existing regulatory framework with concerns to high albedo roofing, for which the National Construction Code sets a maximum solar absorbance of 0.45 for non-residential buildings. Currently, residential buildings are not considered, and the existing provision is a Deemed to Satisfy Provision, which can be circumvented by a Performance Solution implementing a dark roof. The latter would meet compliance in terms of building energy consumption but would also increase urban overheating during the hot season, with all environmental negative consequences. Also, there is currently no provision on the thermal emittance (emissivity) and reference to verification methods. Finally, there is no separate limit for flat and pitched roofs, as in all international building codes implementing cool roofs.

Therefore, in this section, we offered recommendations in view of the consultation leading to the revision of the National Construction Code of 2025. These recommendations include a restructuring of the indicators, including thermal emittance or switching to the Solar Reflectance Index to use a single indicator. The main recommendation is to include a performance requirement on the mitigation of urban overheating, which cannot be circumvented. Then, minimum values for the Solar Reflectance Index, solar reflectance and thermal emittance are recommended for flat and pitched roofs of all buildings (including residential), with a staged approach starting from 2025. The use of aged values is also strongly recommended.

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.

4.7 References

Akbari, H., Levinson, R., & Stern, S. (2008). Procedure for measuring the solar reflectance of flat or curved roofing assemblies. Solar Energy, 82(7), 648–655. https://doi.org/10.1016/j.solener.2008.01.001

Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: increasing world-wide urban albedos to offset CO2. Climatic Change, 94(3–4), 275–286. https://doi.org/10.1007/s10584-008-9515-9

ASHRAE. (2009). ASHRAE Standard 160-2009. Criteria for Moisture-Control Design Analysis in Buildings. American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASTM. (2016). ASTM E 1918: Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field. American Society for Testing and Materials.

ASTM International. (2005). ASTM G 7-05. Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials. American Society for Testing and Materials.

ASTM International. (2009). ASTM C 1549. Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer. American Society for Testing and Materials.

ASTM International. (2011). ASTM E 1980. Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low- Sloped Opaque Surfaces. American Society for Testing and Materials.

ASTM International. (2012). ASTM E 903-12. Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres. American Society for Testing and Materials. https://doi.org/10.1520/E0903-12

ASTM International. (2015). ASTM C1371-15. Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers. American Society for Testing and Materials. https://doi.org/10.1520/C1371-15

ASTM International. (2018). ASTM D 7897-18. Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance. American Society for Testing and Materials. https://doi.org/10.1520/D7897-18

Australian Building Codes Board. (2019). National Construction Code. http://www.abcb.gov.au

Berdahl, P., Akbari, H., Jacobs, J., & Klink, F. (2008). Surface roughness effects on the solar reflectance of cool asphalt shingles. Solar Energy Materials and Solar Cells, 92(4), 482–489. https://doi.org/10.1016/j.solmat.2007.10.011

CEN. (2001). EN 12898. Glass in building. Determination of the emissivity. CEN.

CEN. (2007). EN 15026. Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation. CEN.

CEN. (2011). EN 15976. Flexible sheets for waterproofing. Determination of emissivity. CEN.

Cool Roof Rating Council. (2018). CRRC rated products directory. http://coolroofs.org/products/results

Cool Roofing Rating Council. (2018a). ANSI/CRRC S100-2016. Standard Test Methods for Determining Radiative Properties of Materials. Cool Roof Rating Council. https://coolroofs.org/documents/ANSI-CRRC_S100-2016_Final.pdf

Cool Roofing Rating Council. (2018b). Product Rating Program Manual CRRC-1 (p. 50). http://coolroofs.org/documents/CRRC-1_Program_Manual_-_2018-05-18.pdf

Daniotti, B., Paolini, R., & Cecconi, F. R. (2013). Effects of Ageing and Moisture on Thermal Performance of ETICS Cladding. In V. P. de de Freitas & J. M. P. Q. Delgado (Eds.), Durability of Building Materials and Components (Vol. 3, pp. 127–171). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-37475-3

Daniotti, B., & Re Cecconi, F. (2010). CIB W080: WG3 Test Methods for Service Life Prediction. State of the Art report on accelerated laboratory test procedures and correlation between laboratory tests and service life data. CIB. INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION IN BUILDING AND CONSTRUCTION. http://site.cibworld.nl/dl/publications/w080_wg3_report.pdf

EOTA. (2013). ETAG004 - External Thermal Insulation Composite Systems with Rendering. European Organisation for Technical Approvals. https://www.eota.eu/en-GB/content/etags/26/

ISO. (2003). ISO 9050 - Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors. International Organization for Standardization.

ISO. (2004). ISO 2810. Paints and varnishes – Natural weathering of coatings - Exposure and assessment.

ISO. (2012). ISO 15686-2 - Buildings and constructed assets - Service life planning - Part 2: Service life prediction procedures. International Organization for Standardization.

Jacques, L. F. E. (2000). Accelerated and outdoor/natural exposure testing of coatings. Progress in Polymer Science, 25(9), 1337–1362. https://doi.org/10.1016/S0079-6700(00)00030-7

Kononogova, E., Adibekyan, A., Monte, C., & Hollandt, J. (2019). Characterization, calibration and validation of an industrial emissometer. Journal of Sensors and Sensor Systems, 8(1), 233–242. https://doi.org/10.5194/JSSS-8-233-2019

Levinson, R., Akbari, H., & Berdahl, P. (2010a). Measuring solar reflectance-Part I: Defining a metric that accurately predicts solar heat gain. Solar Energy, 84(9), 1717–1744. https://doi.org/10.1016/j.solener.2010.04.018

Levinson, R., Akbari, H., & Berdahl, P. (2010b). Measuring solar reflectance-Part II: Review of practical methods. Solar Energy, 84(9), 1745–1759. https://doi.org/10.1016/j.solener.2010.04.017

Paolini, R., Terraneo, G., Ferrari, C., Sleiman, M., Muscio, A., Metrangolo, P., Poli, T., Destaillats, H., Zinzi, M., & Levinson, R. (2020). Effects of soiling and weathering on the albedo of building envelope materials: Lessons learned from natural exposure in two European cities and tuning of a laboratory simulation practice. Solar Energy Materials and Solar Cells, 205, 110264. https://doi.org/10.1016/j.solmat.2019.110264

Paolini, R., Zinzi, M., Poli, T., Carnielo, E., & Mainini, A. G. (2014). Effect of ageing on solar spectral reflectance of roofing membranes: natural exposure in Roma and Milano and the impact on the energy needs of commercial buildings. Energy and Buildings, 84, 333–343. https://doi.org/10.1016/j.enbuild.2014.08.008

Shi, D., Zhuang, C., Lin, C., Zhao, X., Chen, D., Gao, Y., & Levinson, R. (2019). Effects of natural soiling and weathering on cool roof energy savings for dormitory buildings in Chinese cities with hot summers. Solar Energy Materials and Solar Cells, 200, 110016. https://doi.org/10.1016/J.SOLMAT.2019.110016

Sleiman, M., Ban-Weiss, G., Gilbert, H. E., François, D., Berdahl, P., Kirchstetter, T. W., Destaillats, H., & Levinson, R. (2011). Soiling of building envelope surfaces and its effect on solar reflectance—Part I: Analysis of roofing product databases. Solar Energy Materials and Solar Cells, 95(12), 3385–3399. https://doi.org/10.1016/j.solmat.2011.08.002

Sleiman, M., Chen, S., Gilbert, H. E. H. E., Kirchstetter, T. W. T. W., Berdahl, P., Bruckman, L. S. L. S., Cremona, D., French, R. H. R. H., Gordon, D. A. D. A., Emiliani, M., Herrera, E., Kable, J., Ma, L., Martarelli, M., Paolini, R., Prestia, M., Renowden, J., Revel, G. M., Rosseler, O., … Destaillats, H. (2015). Soiling of building envelope surfaces and its effect on solar reflectance – Part III: Interlaboratory study of an accelerated aging method for roofing materials. Solar Energy Materials and Solar Cells, 143, 581–590. https://doi.org/10.1016/j.solmat.2015.07.031

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

Synnefa, A., Pantazaras, A., Santamouris, M., Bozonnet, E. M. D., Doya, M., Zinzi, M., Muscio, A., Libbra, A., Ferrari, C., Coccia, V., Rossi, F., & Kolokotsa, D. (2013). Interlaboratory Comparison of Cool Roofing Material Measurement Methods. 34th AIVC Conference.

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. Appendix _Questionnaire. Cool Roof Application _ Barriers and Recommendations

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)

2. High initial installation/application cost *

- ☐ High initial installation/application cost
- ☐ High maintenance cost
- ☐ Lack of government support or incentives
- ☐ Other (please specify):

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

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

Barriers in the Industry

4. Barriers in the Industry (Multiple Answers) *

- [ ] Lack of standardised accreditation
- [ ] Lack of client interest and acceptability
- [ ] Lack of policy
- [ ] Other (please specify):

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

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

Product Barriers

6. Product Barriers (Multiple Answers) *

- [ ] Lack of cutting-edge technologies
- [ ] lack of environmentally friendly products
- [ ] Lack of weather resistance
- [ ] Lack of superior reflectance or emittance
- [ ] Other (please specify):

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

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

Knowledge and Information Barriers

8. Knowledge and Information Barriers (Multiple Answers) *

- [ ] Lack of local research

- [ ] 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): ______________________

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

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

Environmental Barriers

12. Environmental Barriers (Multiple Answers) *

- [ ] Cause glare to surroundings
- [ ] Not accepted aesthetically

☐ 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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