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Green roofs in Australia: review of thermal performance and associated policy development

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Abstract: In Australia, there is an increasing interest in using extensive green roofs to make buildings more sustainable and provide a number of social, ecological, aesthetic and thermal benefits to cities. The potential of green roofs to reduce building energy consumption has been extensively studied overseas in a variety of different climates. However, in Australia the green roof industry is relatively new. There is still very little information on the thermal properties of Australian green roofs and their performance. Further, as a relatively new industry, there is a general lack of specific policies and initiatives to promote green roofs. In this paper, we briefly review the research investigating green roof thermal performance in various climates and analyse policies and actions that have been implemented internationally to foster green roofs with an emphasis on their thermal performance. The results showed that most policies were focused on ecological benefits, such as stormwater runoff reduction, rather than thermal benefits. Many green roof policies had difficulty interpreting the thermal performance of green roofs, because of the dynamic nature of green roof R-values. In this study, the effectiveness of overseas green roof policy is discussed and recommendations how they could be adapted for Australian cities are provided.

Keywords: Green roofs; thermal performance; building; policy.

1. Introduction

Cities, as the locations of substantial resource use and pollution, are increasingly focused on measures to reduce their environmental impacts and carbon footprint (Gill *et al.*, 2007). Globally, buildings consume about 40% of the annual energy consumption and are responsible for CO_2 and NO_x emissions, as most of the energy used is produced by burning fossil fuels (Omer, 2008). Strategies to reduce the environmental impact of buildings include incorporating passive cooling systems (Doulos *et al.*, 2004), adopting energy efficient design and techniques (Sadineni *et al.*, 2011), using recycled materials in construction (Chwieduk, 2003), using or even producing renewable energy (Chwieduk, 2003) and mimicking nature for sustainable design (John *et al.*, 2005). Green roofs, also called vegetated roofs, are increasingly popular worldwide as they can ameliorate some of the environmental impacts of buildings, including energy savings – particularly for low rise buildings (Martens *et al.*, 2008), providing cooling effect and, to some extent, the mitigation of the urban heat island effect (Berardi *et al.*, 2014).

Numerous studies conducted all around the world, have investigated the thermal performance of green roofs. Generally, it has been found that their thermal performance varies across climates and depends on the materials used to construct the green roof and their associated thermal properties (Parizotto and Lamberts, 2011; Schweitzer and Erell, 2014; Zhao *et al.*, 2014). Varying results have been found among different typologies of buildings: generally, low rise buildings, such as one-storey buildings, had the best positive outcomes in terms of energy saving compared to multi-storey buildings, because of high roof-envelope ratio (Martens *et al.*, 2008). As green roofs are relatively new in Australia, we have very little information about their thermal performance. This is complicated by having various climate zones in Australia (Figure 1), implying that green roofs may need to be designed differently to maximise their thermal performance in each climate zone.

This paper reviews research investigating the thermal performance of green roofs across different climates globally, to inform the selection of the most appropriate green roof materials for Australia, and maximise their thermal performance. We also analyse policies and actions implemented around the world to encourage green roof construction, to inform the integration of the thermal benefits into Australian green roof policies including the National Construction Code (NCC).

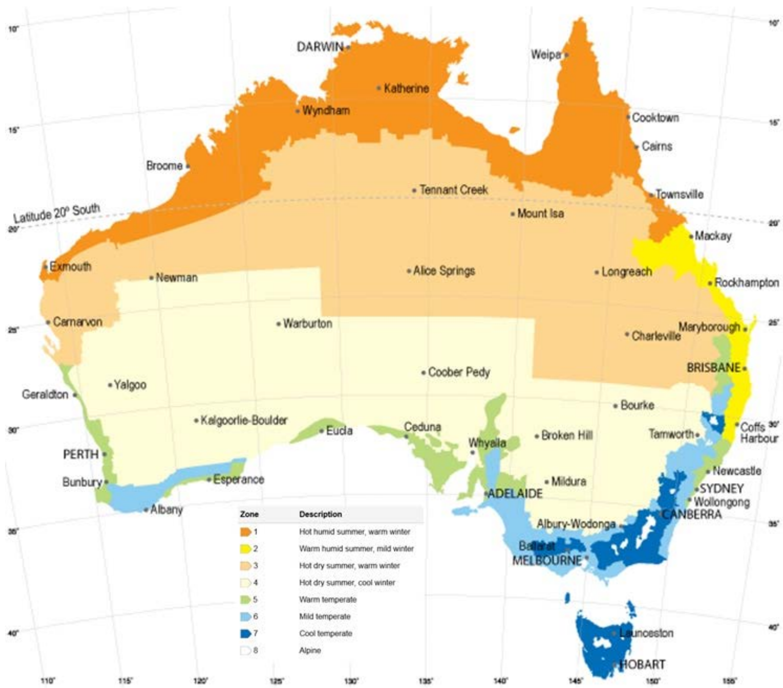

Figure 1: Australian climate zones (ABCB, 2016).

1.1. How do green roofs reduce the thermal load for buildings?

The components of energy balance equations on green roofs differ depending on the conditions of the roofs. For a bare roof, the incoming solar radiation is equal to the sum of four main components: (1) radiation reflected to the surrounding by the roof; (2) heat stored within the roof layers; (3) heat transferred to indoor; (4) heat loss to the surrounding from the roof. For a green roof with plants, the incoming solar radiation is equal to the sum of several components: (1) radiation reflected to the surrounding by plants; (2) radiation reflected to the surrounding by substrate; (3) energy consumed for evaporation, transpiration and photosynthesis; (4) heat loss by leaves; (5) heat loss by the substrate; (6) heat stored within the foliage; (7) heat stored within the green roof layers; (8) heat transferred to indoor. While for conventional roofs the reflectivity and emissivity values are mostly constant over time, this is not the case for green roofs as the thermal characteristics of plants and the substrate change over time. For example, plant density and substrate moisture content strongly affect the values of the energy balance components. The reflectivity of the substrate changes according to its moisture content (Sailor *et al.*, 2008). The cooling benefit provided by the plant transpiration is dependent on vegetation density. Vegetation density, together with the total plant coverage, also reduces the substrate temperature due to shading. Table 1 presents a qualitative summary of the functions performed by green roofs to reduce the building thermal load. In a green roof, conduction, radiation and convection heat transfer mechanisms occur simultaneously with moisture transfer. Quantifying the dynamic heat flux through a green roof is thus complex and requires simplified assumptions, such as one-dimensional heat transfer, to make the model tractable.

Table 1: Green roof functions associated with thermal load reduction (qualitative).

Green roof component	Technique
Vegetation	Direct solar shading provided by the foliage Cooling by plant transpiration which is controlled by leaf stomata Direct solar reflection by the leaves (proportional to reflectivity) Heat loss by the leaves (proportional to emissivity)
Substrate	Providing additional thermal mass Cooling by evaporation of water bounded in the substrate Direct solar reflection by the substrate (proportional to reflectivity) Heat loss by the substrate (proportional to emissivity)

2. Green roof and thermal performance: a brief review

The transient nature of green roof heat fluxes affects the thermal performance of green roofs. The thermal performance of green roofs is most easily demonstrated when only measuring indoor temperature under different roof types (Parizotto and Lamberts, 2011). However to maximise the thermal benefits, attention must also be paid to selection of materials used in the green roof ‘build-up’ (the overall combination of substrates and plants), its design, climate and seasonality.

Most studies of green roof thermal performance prove that they reduce the heating and cooling loads for buildings, but as green roof build-ups used in overseas studies are not necessarily the same as those used in Australia, specific knowledge and experimental set-ups are essential to guarantee full understanding of green roof thermal performance in Australia (Chen, 2013).

Cold climates countries, such as Canada, benefit from green roofs during summer and winter as they reduce both heating and cooling demands (Sadineni *et al.*, 2011). As a proof that the selection of substrates and plants is essential to maximise the green roof thermal performance for cold climates (Zhao *et al.*, 2014), it was found that in summer a thick and light substrate offers higher insulating thermal mass and retention of moisture for evaporative cooling than a thin dark substrate (Liu, 2003). In winter, the thermal advantage is considerably smaller than in summer, because the extra snow layer facilitates the heat loss from indoor to outdoor and drastically reduces the insulation properties of the green roof (Liu, 2003; Zhao and Srebric, 2012). Even doubling the thickness of substrate from 75 to 150 mm, has no significant impact in enhancing the thermal performance in winter (Lundholm *et al.*, 2014).

Studies in hot and wet tropical and subtropical climates found that the vegetation selection, rather than substrate selection, is the green roof component that makes the green roof effective in reducing the energy demand for cooling. A vegetated green roof in Singapore performs better than a non-vegetated roof, which in turn is more effective than a bare roof (Wong *et al.*, 2003). In Singapore, it was also found that low groundcover plants are not the best choice for extensive green roofs when it comes to passive cooling (Wong *et al.*, 2007): shrubs had a better cooling performance (Wong *et al.*, 2003). The advantage of an intensive green roof in hot and wet climates is reported in a few studies (Wong *et al.*, 2003; Darkwa *et al.*, 2013), however the difference is due to having a dense and vigorous vegetated layer (Onmura *et al.*, 2001; Jim, 2012), rather than having a deeper substrate. Although an intensive green roof provides greater thermal mass, only a shallow layer up to 100 mm is needed to reduce heat penetration into the building (Jim and Tsang, 2011). In contrast, for hot and dry climates plant selection is important for enhancing the green roof thermal performance (Dvorak and Volder, 2013; Schweitzer and Erell, 2014), as plants need to survive long drought periods to provide shading. However, employing alternative types of shading rather than plants, such as mesh or lightweight gravel, can still guarantee a passive cooling benefit for green roofs in hot and dry-arid countries (Pearlmutter and Rosenfeld, 2008).

Dense vegetation was also found to be the key attribute for cooling for an extensive green roof in southern Spain, a Mediterranean climate region (Olivieri *et al.*, 2013). However, in temperate north-eastern Italy, substrate thickness and substrate moisture content were found to be the key parameters to enhancing the thermal performance of green roofs (Lazzarin *et al.*, 2005; Nardini *et al.*, 2012).

Greece, with a southern Europe Mediterranean climate, shares some similarities with southern Spain where dense and dark green vegetation performs better than scarce or no vegetation for cooling during summer (Niachou *et al.*, 2001). However, it has also been found that the composition and porosity of the substrate and its thickness can help reduce the heat flux penetrating the roof of a building (Kotsiris *et al.*, 2012). Overall, in the Greek climate it has been found that green roofs are highly effective in reducing summer cooling demands, while they provide no thermal advantage during winter, regardless of the green roof build-up type (Santamouris *et al.*, 2007; Sfakianaki *et al.*, 2009; Theodosiou *et al.*, 2014). This is different to green roofs in cold (Sadineni *et al.*, 2011) and temperate climates (D'Orazio *et al.*, 2012) where a thermal advantage was found even in winter, although smaller than that in summer.

This review illustrates the complexity in determining the best green roof build-up to maximize the thermal benefits of green roofs as they depend on specific location and climate. It may be one reason why green roofs are barely integrated into Australia’s Green Star rating system (Green Building Council Australia), as difficulty interpreting research findings to a local context is a barrier to their uptake and success (Williams *et al.*, 2010). Countries with many climate zones, such as Australia (Figure 1) or China, need to identify through experimentation the best green roof build-up for each zone (Kokogiannakis and Darkwa, 2014; Xiao *et al.*, 2014) as those used in Europe or North America may not be appropriate (Williams *et al.*, 2010). Synthesising research findings from similar climate zones have enabled us to provide initial green roof build-up recommendations across the eight Australian climate zones (Table 2) to maximise thermal performance. However, these initial recommendations should be supported with local experiments as performances also vary with green roof build-up and existing insulation layers (D'Orazio *et al.*, 2012).

The complexity created by different climate zones and associated thermal performance variations in large countries such as Australia, means that developing consistent green roof policies at a national level is challenging. Nonetheless, given the substantial benefits provided by green roofs, both at the individual building scale as well as at precinct scale, there are significant opportunities for policy development. These research findings can potentially support the inclusion of green roofs into Australian building energy rating schemes. Globally, some governments, particularly those with broader sustainability strategies and targets, have developed policies to encourage or mandate green roof installations. The policy perspectives of green roofs are considered in the following section.

Table 2: Preliminary green roof build-up recommendations to maximise the thermal benefits of green roofs across the eight Australian climate zones.

Climate zone (ABCB, 2016)	City / Town	Recommended green roof build-up
1 Hot humid summer, warm winter 2 Warm humid summer, mild winter	Darwin, Cairns Brisbane, Mackay	Extensive green roof (100 mm) with dense and vigorous vegetation
3 Hot dry summer, warm winter 4 Hot dry summer, cool winter	Alice Springs Mildura, Kalgoorlie	Extensive green roof (100 mm) with drought tolerant plant species
5 Warm temperate 6 Mild temperate	Sydney, Perth Melbourne, Adelaide	Extensive or semi-intensive green roof (150 mm) to maximise moisture retention
7 Cool temperate 8 Alpine	Canberra, Hobart Cabramurra	Semi-intensive green roof (>200 mm) with porous substrate and selected plants

3. Policy perspectives

Internationally, cities and countries with more experience in the installation, operation and maintenance of green roofs, have a range of policy approaches to encourage or mandate the use of green roofs. We now provide a brief overview of policy approaches internationally, and highlight Australia’s few examples of green roof policies, before making recommendations for further policy development in the Australian context.

3.1 Green roof policies: an international perspective

Green roof policies have been applied extensively in many countries in the northern hemisphere, utilising a range of policy instruments. Policy instruments can be categorised into four different types: information and advocacy; incentives; government demonstration and provision; and regulation (Maddison and Denniss, 2009). Most issues, including environmental issues, usually require a range of policy instruments to address the different types of barriers and challenges that are limiting the adoption of the desired practices (Taylor *et al.*, 2012; Dovers and Hussey, 2013). Policy measures may be either binding or voluntary, and may take the approach of regulating minimum standards or providing incentives for best practice.

In Germany, where there has been substantial experimentation, innovation and development of green roof techniques since at least the 1970s and 1980s (Appl, 2009), mandatory green roof regulations have been in place at local and national levels for more than 30 years (Ansel, 2015). Several North

American cities, including Toronto, Chicago and Portland have employed a range of policy instruments to successfully promote green roof installations in urban areas (Carter and Fowler, 2008). Most of these policies aim to promote the ecological benefits of green roofs, such as stormwater runoff reduction and provision of biodiversity habitat, rather than energy savings associated with the insulating value of green roofs (IMAP, 2014).

Internationally, most green roof policy mechanisms are based on regulatory requirements, direct and indirect incentives (Shiah, 2011). There appears to be less focus on information and government provision mechanisms, potentially in part because the familiarity in these cities and countries with green roofs decreases the necessity for these types of public policy mechanisms. Examples of green roof policy mechanisms across each of the four mechanism types are shown in Table 3.

Table 3: Green roof policy mechanisms: international examples.

Policy instrument	Advocacy	Incentive	Government provision	Regulation
Community information, engagement, participation	✓			
Guidelines and toolkits	✓			
Incentives during the planning process for proposals that incorporate green roofs: • Increased floor area ratios • 'Green door' fast tracking of planning approvals • Waiving planning fees • Exempting certain works related to green roofs		✓		
Stormwater fee discount with increased pervious surfaces		✓		
Grants, rebates, financing for installation		✓		
Leadership, including demonstration green roofs			✓	
Integrated government decision-making on urban infrastructure and land use planning			✓	
Integrated government decision-making: ensure existing regulations do not pose a barrier for green roof installations			✓	
Mandatory green roofs/rooftop landscaping on all new buildings (may only apply to specific building types, such as commercial, multi-residential, or to buildings above a certain threshold area)				✓
Planning scheme overlays (identifying specific areas for mandated green roofs on new buildings)				✓
Green building certification (voluntary or mandatory sustainability rating schemes)		✓		✓
Data collection, monitoring, evaluation	✓		✓	
Research	✓		✓	
Awards, recognition programs	✓	✓	✓	

3.2 Green roof policy approaches in Australia

Green roofs are still relatively rare in Australia, and policies to promote them are also rare (Williams *et al.*, 2010). However, there are recent initiatives indicating a growing interest in encouraging green roof installation. In April 2014, the City of Sydney adopted its 'Green roofs and walls policy', the first of its kind in Australia (City of Sydney, 2014). Supporting its policy, the City of Sydney has also developed a range of information resources and technical guidelines (Table 4). Inner Melbourne councils (Cities of Melbourne, Port Phillip, Stonnington and Yarra) in partnership with the Victorian state government and the University of Melbourne, developed a technical guide to support green roof planning, design and installations (DEPI, 2014), and undertook a review of policy options for green roofs (IMAP, 2014). The policy options that were identified focused on mechanisms to encourage installation of green roofs. Whilst regulatory mechanisms were canvassed in the review (IMAP, 2014) pp 44-53), at the time of writing (June 2016), none of these had been mandated by the councils involved. The organisation of regular 'Canopy' forums by the City of Melbourne aims to encourage green roof installations and foster green roof industry development (Table 4). At a national level, the Green Building Council of Australia has included green roofs as a 'creditable feature' in the 'Green Star – Design and As Built' rating system, the voluntary sustainability certification for new buildings in Australia (GBCA, 2015).

Table 4: Australian green roof policies and programs.

City	Policies and programs
Sydney	• Green roofs and walls policy, 2014. Key mechanisms include: o Leadership, awareness raising, demonstration sites on council buildings o Information resources for technical and general information o Development of guidelines and standards o Technical advisory panel o Promotion and training o Support for research partnerships o Identification of opportunities in existing planning scheme and local planning controls, regulations, environmental upgrade agreements (EUAs), rating tools o Monitoring • Implementation plan 2014 • Design guide • Resource manual • Listing of green roof locations in Sydney on website
Melbourne	• Growing Green Guide, 2014: industry knowledge and academic research: technical manual, case studies • Policy options background paper, 2014: international case study research; application to Victorian/metro Melbourne policy and planning; recommendations for more research in Australia to support establishment of min standards specifications • 'Canopy' green roof seminar series: industry network facilitation and information dissemination/generation

Given the early stage of green roof research and practice in Australia, mandating green roof installation through policy regulations would be premature, because there is not sufficient data to allow specification of minimum performance standards, and the construction industry (including green roof specialists) is not yet developed enough to support wide-scale installation and maintenance. In addition, with perhaps the exception of stormwater retention, there is a lack of research data to enable the definition of minimum standards for green roof technical and ecological functions, including thermal performance. This is necessary if financial incentives are offered as minimum standards ensure the quality of installation and to reduce the risk of tokenism or abuse of subsidies (Ansel, 2015). The immaturity of the industry also means that there is uncertainty for developers in the costs of installation and maintenance, and lack of understanding about why cost estimates can vary significantly between different suppliers and installers. Until cost benchmarks exist, there would be significant industry opposition to mandating green roofs for new developments.

Given green roofs are still considered a novel innovation in Australia, policies should therefore focus on addressing key barriers to uptake; including provision of information, building awareness and public interest; technical capability and expertise in green roof installation, operation, maintenance; and financial support and incentives for installation and maintenance. In addition, policy makers should review building and planning regulations to remove existing policy barriers to green roof installations and ensure existing policies do not provide barriers to uptake.

Demonstrations sites are useful for this purpose. A green roof installed in Athens (Georgia, USA) was used as a test study to monitor stormwater runoff and rooftop temperatures. The data collected provided evidence of the benefits from green roofs and enabled policy makers to mandate policy recommendations at federal and local levels, in particular to control stormwater (Carter and Fowler, 2008). Similar test studies could be undertaken in Australia to collect green roof thermal data from different Australia climate zones. This will test and validate the best green roof build-up for every different climate zones (as recommended in Table 2), and will provide sufficient data to support green roof policy measures, including building energy rating schemes.

4. Conclusion

Thermal performance of green roofs varies globally across different climates; research is providing evidence of the most suitable green roof build-up to maximise their thermal benefits in different climates. Understanding and assessing the thermal performance of green roofs for Australian climate zones will not only help integration of the green roof building component into building energy rating schemes, but also will contribute to implementation of green roof policies and promotions in Australia.

Policy development and the selection of appropriate policy instruments needs to address the local context, the barriers to uptake and the state of development of the technology and the associated industry (construction, installation, operation and maintenance). Industry development and policy development are mutually supportive. The capital city councils of Australia's largest cities, Sydney and Melbourne, have begun to address some of the barriers to green roof implementation, uptake and success (Williams *et al.*, 2010; Zhang *et al.*, 2012) through green roof policy development and integrated programs of information and industry support.

To support continued policy development and strengthened policy prescriptions, further research on the technical performance of green roofs in Australia's different climate zones is required, as well as fostering community interest and industry development.

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