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Green roof retrofit potential in the central business district

Sara J. Wilkinson, School of Life & Environmental Sciences, Faculty of Science and Technology, Deakin University, Melbourne, Australia

Richard Reed, School of Architecture & Building, Faculty of Science and Technology, Deakin University, Melbourne, Australia

Abstract

Purpose – The purpose of this paper is to illustrate the potential for green roof retrofit to commercial buildings in a city centre to property managers and other property professionals.

Design/methodology/approach – This paper addresses the research question: what is the potential of existing buildings in the CBD to accommodate a retrofitted green roof? Furthermore, it questions how many buildings are suitable for green roofs? The researchers compile a unique building database incorporating information about 536 commercial buildings and evaluate the potential suitability of each building to undergo a green roof retrofit. Assisted by other commercially available databases and software, the researchers are able to assess each roof based on criteria derived from an extensive literature review.

Findings – A relatively small proportion of roofs are found to be suitable, partly a result of local climate conditions and rainfall patterns, and the physical property stock. On a purely physical assessment, only a very small proportion of CBD stock is found to be suited. These buildings are most likely to be in low secondary locations, ungraded or B grade buildings, privately owned, concrete framed and not overshadowed by adjoining properties.

Practical implications – Property managers and other property professionals can now determine the potential of their portfolio stock for green roof retrofit based on the review of building attributes required for success adaptation in this paper. It possible that greater potential for green roof retrofit exists in the suburbs or regional towns where lower rise buildings may reduce the amount of overshadowing found in city centres. Follow-up research could focus on a comparison of regional and suburban developments.

Originality/value – This is the first study of its kind and has assessed such a large number of buildings for their suitability for green roof retrofit; the findings provide a reliable guide for policymakers regarding the potential number of city centre buildings which would be possible to retrofit. Such findings should influence policymaking and incentives to target effective sustainability policies with regards to existing buildings.

Introduction

More and more one option considered by building owners to increase sustainability of existing building stock is whether to retrofit a green roof. Australia, like many other developed countries, needs to increase the adaptation of the existing commercial property stock to reduce building related greenhouse gas emissions (CSIRO, 2002). At the same time
the City of Melbourne is planning to become carbon neutral by 2020 (Aecom, 2008; ARUP, 2008a) and a target of 1,200 building adaptations has been established to deliver 24 per cent greenhouse gas reductions through sustainability measures implemented to existing buildings. Some of these carbon emission reductions could be achieved by retrofitting green roofs. Given that Germany had over 10 million square metres of green roofs by 1996, it must be asked: are we missing an increasingly important opportunity for green roof adoption in Australia?

**Green roofs**

A starting point is to posit what exactly is a “green roof”? It can defined as a roof that uses plants which range from but do not exclusively include grass, moss, lichen, sedum, trees, shrubs, flowers and bushes. Green roofs are referred to by a number of different labels, such as eco-roofs, nature roofs or roof greening systems. In summary green roofs are a living vegetated roofing alternative to traditional impervious roofing materials. A green roof is comprised of the following components: a roof structure; a waterproof membrane or vapour control layer; insulation (i.e. if the building is heated or cooled); a root barrier to protect the membrane (i.e. made of gravel, impervious concrete, polyvinylchloride (pvc), thermoplastic polyolefin (tpo), high-density polyethylene (hdpe or copper); a drainage system; a filter cloth (non-biodegradable fabric); a growing medium (soil) consisting of inorganic matter, organic material (straw, peat, wood, grass, sawdust) and air; and plants. See Figure 1 for a typical green roof cross-section.

Green roofs are either extensive or intensive. Extensive green roofs are roof gardens which typically provide space for people and the depth of soil or substrate layer provided varies between 50 to 200 mm and requires artificial irrigation. Intensive roofs often require a deeper planting medium greater than 150 mm. There is a third type, a semi intensive green roof which is a hybrid of the intensive and extensive roofs. The following are attributes of extensive and intensive green roofs, as sourced by the author:

1. **Extensive green roof**:
   - shallow growing medium (<150 mm);
   - lightweight structure to support roof;
   - cover large expanses of rooftop;
   - requires minimum maintenance;
   - lower capital cost;
   - not usually recreational;
   - accessible or inaccessible;
   - does not usually require irrigation; and
   - minimum structural implications for existing buildings.

2. **Intensive green roof**:
   - deeper growing medium (>150 mm);
   - heavier roof structure required to support roof;
   - small trees and shrubs feature;
   - more maintenance required;
   - more expensive;
   - more common in tropical climates; and
o accessible or inaccessible.

It is vital to keep the plants alive in the long-term and this is a challenge because it requires an active and ongoing commitment to a maintenance and irrigation or watering regime (Skyring, 2007; University of Sheffield, 2005). Standard soils are not used because they are too heavy for roof structures and a calculated ratio of aggregate (e.g. shale, vermiculite), organic materials, air and water is used. The correct growing medium is critical and may be challenging in some Australian cities due to climatic conditions particularly excessive seasonal rainfall (e.g. as in the Northern Territory or Australia) or minimal rainfall (e.g. as in Victoria).

Drivers behind the adoption of green roofs

There are many benefits of green roofs in the literature, one of which is the reduction of external noise for occupants since the substrate and vegetation absorb airborne noise. Water harvesting is possible from green roof systems. Thus it is possible to design the system to collect rainwater which can be used to irrigate the planting systems or, in some climates, can be used within the building to reduce overall water usage from the mains systems. With regards to stormwater management it may be possible for between 50-85 per cent of stormwater volume to be reduced. Furthermore, the percolation and filtering of the stormwater improves the quality of stormwater entering the main drainages systems.

Energy conservation of between 15-30 per cent could be recorded in buildings with green roofs. As a result of less energy used, greenhouse gas emissions are accordingly lessened. There is variation in the amount of energy conserved due to variations in climates, variation in the depth of green roof substrates and also differences in base building construction and performance (Niachou et al., 2001; University of Sheffield, 2005). Green roofs have the potential to lower surface roof temperatures by 10-15.5 degrees Celsius, which means less heat gain occurs inside the building and less cooling is required as a result. Lower temperatures are recorded where darker vegetation is used (Niachou et al., 2001).

The reductions in energy usage and external surface temperatures of roofs can also lead to a reduction in the “urban heat island effect” of city centres. The heat island is caused when the heat from the sun is absorbed into buildings by the roof and then released back into the air leaving urbanised city centres being one or two degrees hotter than outer suburbs and rural areas.

For building owners seeking to promote sustainability and to offset the impact of obsolescence as well as gaining accreditation through the green rating tools, some such rating tools as the US designed LEED tool does award points for green roofs. A further benefit of green roof is pollution abatement. Airborne particulates are caught within the vegetation and the pollutants are filtered naturally through the planting systems. Air quality is improved with the reduction of nitrous oxides, volatile organic compounds by plants as well (Peck and Callaghan, 1999). A further environmental advantage is that green roofs contribute to the bio-diversity within the city and creates habitats for birds and invertebrates.
Advocates of green roofs also posit that green roofs have high aesthetic values, adding colour and vibrancy to, often colourless roof lines. It is known that humans derive enjoyment from being able to view natural environments and the provision green roofs allows building occupants in dense urban centres the chance to enjoy viewing green roofs and gardens. It has been argued that other community benefits are increased worker health, productivity and creativity (Peck and Callaghan, 1999).

On a practical level, green roofs can potentially extend the useful life of the base roofing material because it is covered and protected from the aging effects of exposures to the atmosphere, weather and pollutants (University of Sheffield, 2005). Furthermore, financial savings are often possible because less maintenance of roof coverings are required. Other economic benefits are the employment opportunities created for a wide range of professionals including suppliers and manufacturers of green roofing materials as well as engineering professionals.

Barriers to green roofs

When considering the benefits of a green roof and that the technology has been available for well over two decades, it can be asked: why are there not more green roofs on buildings in our city centres? The barriers to green roof uptake is perceived to be a lack of awareness within the development industry, as well as a poor appreciation by government officials and general public regarding the benefits of green roofs. In addition there are few incentives in support of green roof technology diffusion even though there are recommendations for an incentive lead policy as opposed to a regulatory approach (Skyring, 2007). In Basel, Switzerland the planning policy requires that all new flat roofs are green roofs and thereby presents a very pro-active approach to encouraging green roof technology.

Another perceived barrier is the higher construction costs associated with new green roofs. Skyring (2007) estimated that costs are double those of a standard roof construction. Figures for the costs of retrofitting green roofs to existing buildings are not available. Historically, the market does not recognise or appropriately account for the benefits of green roofs, and rather than adopting a life cycle assessment which includes accounting for the environmental and social benefits, typically, the economic case is the only one considered (Peck and Callaghan, 1999).

There are also barriers in adopting new methods and techniques in property and construction. There is no long-term documented examples of green roof technology on which to draw upon. For example, whilst claims of lower maintenance costs appear reasonable and sound there is no historic evidence to conclusively support this claim. When green roof technologies are adopted within building codes and technical standards are produced more then it is envisaged that confidence will be enhanced in the sector about green roofs.

Finally, a major issue is related to the technical data limitations when calculating the benefits associated with green roofs. As noted above the range of benefits achieved through the installation of green roofs varies according to a building’s location, climate and
construction type. Therefore, the anticipated savings may not be fully realised in practice and this factor alone may deter some from adopting the measure.

In summary, the drivers and barriers to green roof are environmental, economic and social are listed in Table I.

Building attributes for green roofs

Suitability for a green roof retrofit is dependent on factors such as the roof type, size and slope. Extensive and intensive roofs require a minimum slope of 2 per cent and roofs with less than 2 per cent slope require additional drainage measures to avoid water logging. Additional requirements include good drainage, lightweight growth media, waterproofing, additional structural support, rainwater harvesting and the use of drought or heat tolerant plants. Longevity of the structure, drainage and waterproofing system is essential because replacement costs are high. Green roofs are designed to last a minimum of 50 years which is approximately twice the life cycle of a roof covering such as bitumen for example. Overall, the following criteria are taken into account when determining whether a roof is suitable for retrofitting:

- position of the building;
- location;
- orientation of the roof;
- height above ground;
- pitch;
- weight limitations of the building;
- preferred planting;
- sustainability of components; and
- levels of maintenance.

The first six criteria are purely physical attributes of buildings and the last three are related to building owner and/or client desires and the ability to maintain the green roof.

Other decision considerations

In addition, other factors influence the potential to retrofit a green roof. For example, climate affects the type of green roof it is possible to provide and Australia, which has eight climate zones within its national boundary, is one of the most climatically diverse nations. Owners and/or property/facility managers need to consider maintenance requirements. Long-term maintenance is essential and a minimum five-year maintenance contract is recommended to ensure the correct processes are undertaken and that planting is properly established. Finally, there is the budget to consider, which includes how much is the building owner willing to pay for a green roof. A whole life cycle costing approach may be useful to determine the overall costs and may offset a higher initial construction and installation costs.

Research questions, aims and objectives

This research adopted a straightforward research question, namely:
RQ1. What is the extent of the potential to retrofit green roofs within the city of Melbourne central business district (CBD)?

The aim was to undertake a comprehensive audit and examine the whole CBD building stock and identify buildings which contained the attributes or characteristics required for green roof adaptation. Melbourne was selected as the city for the case study as it is representative of a major global city in a developed country. Similar development patterns are found in other Australian city centres such as Sydney and to a lesser extent Perth and Brisbane. Furthermore, Melbourne is considered to contain similar buildings to other global cities in the US and elsewhere.

Research methodology

The research methodology involved the compilation of a detailed building database which focussed on the building stock in the Melbourne CBD. The database was compiled using multiple sources such as existing commercial databases such as Cityscope, and publicly available databases such as PRISM (Victorian Government) and the Heritage database. In addition data from the Property Council of Australia (PCA), Google Earth (www.google.com.au/earth) and Google Streetview (www.google.com.au/maps) was used by the researcher to gather building related data. Finally, the researcher made visual inspections and photographed CBD buildings. Following a comprehensive validation phase the final building database contains 526 commercial buildings in the Melbourne CBD.

The criteria below are taken into consideration when determining whether a roof is suitable for a green roof retrofit:

- position of the building;
- location of the building;
- orientation of the roof;
- height above ground;
- roof pitch;
- weight limitations of the building;
- preferred planting;
- sustainability of components; and
- levels of maintenance.

All of these criteria above were considered, with the exception of the preferred planting options, sustainability of components and levels of maintenance. This is an exploratory study to determine the extent of the potential for green roof adaptations within the Melbourne CBD and therefore details on the structural strength of the buildings was not collated which considering the number of buildings in the analysis.

A research objective was to determine whether a green roof on a particular building was:

- a viable option;
- not a viable option; or
- possibly a viable option.
Using the “Google Map” (www.google.com.au/maps) search engine it was possible to view the roof from close quarters. It was possible to determine whether the roof was steeply pitched or otherwise, whether there was plant and services equipment on the roof which might have a detrimental effect of planting, or if the building was overshadowed partially i.e. completely or not at all. The compilation of this detailed database of building characteristics enabled the study to evaluate the potential for green roof retrofit to existing CBD buildings. The database was compiled and verified using Microsoft Excel with the analysis undertaken in SPSS version 17. The results of this research will enable stakeholders such as the City of Melbourne to evaluate on a cost-benefit analysis, the desirability of developing and pursuing incentives to roll out a programme for green roofs in the city. The results allow other municipal authorities to reflect on the potential of their stock to accommodate a retrofit programme.

Data analysis

The CBD stock

The first section of the analysis provided an overview of 526 CBD buildings in the database. Surprisingly the age profile examination revealed an average age of 61 years with the oldest building built in 1853 and the most recent in 2005. Note that new buildings have been completed since 2005 but are not in the database which covered the time period from 1850 – 2005. The top ten years for the construction of new buildings are recorded in Table II. Only two entries are pre-war and this is reflective of considerable post-war construction in the CBD. Since 1940 there were a total of 302 (or 60.4 per cent) new commercial buildings built in the city centre.

There is a consensus that minor adaptations are required within a five-seven year period after construction, with major works being carried out between 20-25 years when services require replacement (JLL, 2005; ARUP, 2008b). Given the high number of buildings constructed from the 1960 s onwards (237 buildings), there is a large amount of stock which would be due for updating and adaptation and consideration of retrofitting green roofs.

When considering building height, an important issue in green roof technology, the average number of stories is three and most buildings are low rise and partially or totally overshadowed in many instances. Overall, 405 buildings are four stories high or less and 68.1 per cent of the stock is ten stories high or less. The data confirmed that 4.4 per cent of the buildings are between 21 and 30 stories in height and 2 per cent are 31 to 40 stories high, 0.8 per cent is 41-50 stories high and 0.2 per cent are up to 66 stories high. Figure 2 show the number of storeys in all buildings and reveals most are low to medium rise. A definition of what is a high rise building is relatively general and refers to metres in height rather than number of stories. In Australia the PCA uses an office building quality matrix which classes buildings from premium (the highest grade) through to A, B, C and D grades (the lowest grade). Part of the grading criteria is net lettable area (NLA) and not the number of stories (PCA, 2006). According to some definitions, buildings over approximately seven stories (or 23 metres high) are in high rise and those over 80 metres or approximately 20 stories are deemed skyscrapers.
Figure 2 shows that a minority of all building have high or sky-rise heights which cast shadows over adjoining lower buildings as the sun moves across the sky during the day. Such an arrangement of buildings could mean that existing buildings which have adequate structural strength to accommodate retrofitting with green roofs may be unsuitable because of overshadowing which adversely affects planting.

During the analysis consideration was also give to the site and the location of the building (Kincaid, 2002). Within the Melbourne CBD, locations are categorised as “prime” (the best location), “low prime”, “high secondary”, “secondary” and the lowest grade “fringe. 7.6 per cent were located in the prime zone, 15.2 per cent in the low prime area, and 7 per cent in the high secondary area – thus, 29.8 per cent of all properties were located in the higher grade location zones. The highest proportion (43.2 per cent) was is in the low secondary area and nearly a quarter (24.7 per cent) was located in the fringe area at the periphery of the CBD grid. Figure 3 illustrates the distribution of the database properties within the five CBD zones.

Orientation determines how much exposure to sunlight the roof gets. In a sample of 72 buildings in the database, an examination of site orientation revealed that most face east (41.17 per cent) followed by west-facing (30.88 per cent), south-facing (16.17 per cent) and finally north-facing buildings which comprised 11.76 per cent of the sample. In the southern hemisphere north-facing properties will be exposed the most to direct sun. Therefore, it appears that a large number will only have partial exposure to sunlight, even before overshadowing is considered (Figure 4).

Research conducted by Povell and Eley (cited by Markus, 1979) and Isaac's (cited by Baird et al., 1996) noted that the number of site boundaries (i.e. whether a building is adjoined to another or others) determines the ease of green roof adaptation. Buildings which are not attached to others tended to be easier to adapt because of access and the lack of disturbance caused to neighbours (Kincaid, 2003). The properties were predominantly bounded on two sides (47.4 per cent), with 21.9 per cent bounded on one side only and 18 per cent bounded on three sides. Only 12.1 per cent were bounded on no sides by any properties or free-standing. Overall, most properties in the sample were not affected adversely by attachment to other buildings or restricted access for construction works, and are suited for retrofitting activity.

Overall 60.6 per cent of commercial buildings in the Melbourne CBD have framed structures. Concrete framing is preferred over steel frame construction in Melbourne and the majority of buildings are constructed using concrete. The remaining 39 per cent of buildings are of traditional load-bearing brickwork and/or stone construction. Note that the buildings with concrete frames are more likely to be suitable for retrofitting with extensive green roof systems and this analysis confirmed there was good potential for minimal structural changes to be undertaken to most CBD buildings. Note that a full structural appraisal would be required on an individual building basis to determine structural suitability for retrofit and to some extent this is a limitation of this research approach. In the process of conducting the analysis there were limited resources undertake detailed structural appraisals of individual buildings. The remaining building criteria of preferred
planting, sustainability of components and levels of maintenance were not considered in depth in this research and therefore represent some of the limitations of this approach.

Green roof potential

The next stage of the research involved a visual inspection of the roof using the Google Earth and Google Map softwares (www.google.com.au/maps) where aerial views facilitated close examinations of building rooftops. This process was assisted by practical experience associated with the primary researcher who is a chartered building surveyor with 22 years’ post-qualification experience. An evaluation of the potential of each roof for retrofitting with green roof technology was undertaken, where the evaluations called for identification as one of three classifications, namely:

1. “yes”;
2. “no”; or
3. “don’t know”.

The evaluation was based on roof pitch i.e. those pitched above 30 degrees and below 2 per cent were deemed unsuitable. The amount of rooftop plant especially equipment which vents air from the building and the provision of rooftop window cleaning equipment was taken into account, where coverage exceeded 40 per cent of roof area the roof was deemed unsuitable for retrofit. Another criterion was roof construction, and lightweight construction was deemed unsuitable. The results in Table III show that 15 per cent of the buildings were considered suitable for retrofit with green roof technology. A relatively low 4.8 per cent of buildings were not classed with yes or no, and a significant percentage of 80.2 per cent were not considered suitable for retrofit based on the criteria above.

The final stage involved an analysis of overshadowing of the stock (see Table IV) where orientation and the proximity of other taller buildings was also taken into account. The analysis identified that 39.3 per cent of the buildings were overshadowed and 36.3 per cent were partially overshadowed. Only 24.4 per cent were not overshadowed at all. Therefore, approximately 75 per cent of the existing stock is considered unsuitable for green roof retrofit on the basis that insufficient sunlight reaches the rooftop for planting to flourish.

Another influencing factor is the local weather conditions with regards to water availability. For example, in Melbourne and throughout many regions in Australia there has been an ongoing drought for over ten years and the extremely low levels of precipitation ensure growing vegetation on green roofs is challenging. In other words, it could be argued that more water would be drawn out of the main system to maintain planting, thereby further diminishing already low stocks. If buildings were simultaneously fitted with greywater recycling systems then previously lost water could be diverted to rooftop roofing systems and green roofs might be viable. However, this option may place a further cost burden on owners.

Bi-variate analysis of green roof criteria
A bi-variate analysis of building attributes and green roof criteria established to identify buildings deemed most likely to support green roofs in the CBD. Figure 5 shows the location of buildings considered most suitable for green roofs is situated in the low secondary zone in Melbourne. Equally, the greatest amount of unsuitable stock was also located in this zone.

Figure 6 confirms a minority of commercial buildings in the Melbourne CBD have historic listings which means that alterations have to comply with strict heritage guidelines and therefore this portion of the stock, regardless of suitability for green roof retrofit was eliminated. Of the remaining non-listed building stock, less than a third is overshadowed and has acceptable exposure for a green roof retrofit. Over a third of the buildings have partial overshadowing and with more detailed analysis some of this group may have sufficient sunlight exposure to support green roof vegetation.

Figure 7 shows the relationship between roof overshadowing and PCA office quality grade (ranging from premium as the highest grade down to D as the lowest grade). Most buildings in the population are ungraded and therefore could have a low quality of construction and maintenance. Of the graded buildings, the most suitable groups are B grade stock, followed by C, A, D and finally premium stock. Premium stock with the high demands for services use rooftops for plant and equipment. The Premium, A and B stock is most likely to be owned by institutional investors and larger organisation who are more likely to adopt CSR and are more likely to pursue green retrofit than the private individuals who own the bulk of the C, D and ungraded stock. Owners of B grade stock seeking to re-brand their building as green, to attract new tenants and increase rental returns may be tempted to specify green roofs.

After a correlation analysis was conducted of the building construction type, roof overshadowing and green roof option (see Figures 8 and 9), it was apparent that concrete properties are more suited to green roof adaptations. This is primarily because they require minimum structural alterations to accommodate the additional weight of the roof system.

Figure 10 shows that when ownership is taken in to account and correlated with overshadowing, most stock is privately owned in the CBD and therefore policymakers will be challenged to target appropriate incentives this disparate group. The next largest group are the institutional owners who are more likely to undertake sustainable retrofits. The government/education sector are the smallest group, however if their financial budget permits they are also quite likely to be pro-sustainability and keen to consider a retrofit green roof. The groups have different profiles. More institutional stock is overshadowed partially and least totally, where in contrast private stock is mostly overshadowed and therefore most likely to be low to medium-rise stock. Least private stock has no overshadowing. In the government sector stock a similar profile exists although affecting a much smaller proportion of buildings.

Findings

This research involved the compilation of a unique database which examined in detailed the characteristics of 526 buildings. The study has produced six key findings in relation to green roof retrofit potential in the Melbourne CBD as follows:
1. At a starting point approximately 15 per cent of the commercial buildings in the database were considered suitable for retrofitting with green roof technology.
2. Only 3.1 per cent of roofs have a north facing orientation, are not overshadowed and are physically suitable for a green roof adaptation.
3. Low secondary locations offer highest potential for green roof retrofits.
4. Ungraded stock and B grade stock are least likely to be overshadowed.
5. Concrete framed stock is more suited to extensive green roof retrofit.
6. The highest amount of stock which is not overshadowed is in private sector ownership.

Conclusions and recommendations

Social, economic and environmental arguments supporting widespread adoption of green roof technology are clear and convincing, however barriers to uptake do exist such as lack of incentives and a general lack of awareness. On a purely physical assessment of potential for retrofitting existing buildings a very small proportion of CBD stock in Melbourne is found to be suited. These buildings are most likely to be low secondary locations, ungraded or B grade buildings, privately owned, concrete framed and not overshadowed by adjoining properties.

There were limitations which affected this research. First, it was not possible to incorporate three of the nine criteria for green roofs in the analysis, namely preferred planting, sustainability of components and levels of maintenance. These attributes were considered to be outside the scope of this research which predominantly was to establish the physical potential of existing buildings to retrofit green roofs. As such, this is deemed to be a minor limitation. The second limitation was that no structural calculations were undertaken to assess roof loads of any buildings because of the time and costs associated with such a methodology. The structural suitability has been assessed on whether the building frame and roof is constructed of concrete and also based on a retrofit with an extensive (i.e. lighter weight) green roof.

A total of 526 buildings were analysed and only 78 buildings appeared to be suitable for green roof technology, therefore it can be concluded there is very limited potential for green roof retrofit on a wide scale in the Melbourne CBD. This limitation is further compounded because most of the physically adaptable stock is in private ownership. The stock also is typically ungraded or B grade stock which is unlikely to be targeted for expensive retrofitting, especially with an external feature such as a green roof. The research question has been answered with a high degree of reliability given the extensive analysis of the high number of CBD buildings and also the thorough expert lead visual inspections of each building. The research aims has been achieved and building attributes of location, height, construction (e.g. weight limitation), building grade, roof orientation, roof pitch, proximity of roof plant and equipment and amount of overshadowing form adjoining stock have been thoroughly considered in the analysis of green roof potential.

Overall, the proportion of potentially suitable stock was found to be low and it possible that greater potential for green roof retrofit exists in the suburbs or regional towns where lower rise buildings may reduce the amount of overshadowing found in city centres. Follow-up
research could focus on a comparison of regional and suburban developments. Furthermore, international comparisons could determine whether cities with a different pattern and age of development offer more or less potential for green roof retrofit. In the meantime, it appears that building owners and policy makers should look elsewhere for carbon emission reductions from green roofs in the Melbourne CBD.

![Figure 1: Typical green roof section](http://www.landcareresearch.co.nz/research)

**Source:** http://www.landcareresearch.co.nz/research

*Figure 1* Typical green roof section
Figure 2: Number of storey's in Melbourne CBD buildings
Figure 3 Building location

**Key:**
1 = prime
2 = low prime
3 = high secondary
4 = low secondary
5 = fringe
Figure 4: Building orientation in Melbourne CBD
Figure 5: Green roof option and building location.
Figure 6 Roof overshadowing and historic listing
**Figure 7** Roof overshadowing and PCA grade

**Source:** Author
Figure 8: Roof overshadowing and construction type
Figure 9 Green roof option and construction type
Figure 10 Roof overshadowing and ownership

Source: Author
<table>
<thead>
<tr>
<th>Drivers</th>
<th>Barriers</th>
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</thead>
<tbody>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
</tr>
<tr>
<td>Reduction of noise pollution</td>
<td>Few incentives</td>
</tr>
<tr>
<td>Water harvesting</td>
<td></td>
</tr>
<tr>
<td>Stormwater management</td>
<td></td>
</tr>
<tr>
<td>Energy conservation and greenhouse gas emissions reductions</td>
<td>Perceived as high cost</td>
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<tr>
<td>Reduces heat island affect</td>
<td></td>
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<tr>
<td>Pollution abatement</td>
<td></td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td></td>
</tr>
<tr>
<td>Credits available in known environmental rating tools</td>
<td></td>
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<tr>
<td>Less maintenance required during roof life cycle</td>
<td></td>
</tr>
<tr>
<td>Less energy used lowers bills</td>
<td></td>
</tr>
<tr>
<td>New employment opportunities for a wide range of professionals including suppliers and manufacturers of green roofing materials</td>
<td></td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td></td>
</tr>
<tr>
<td>High aesthetic values provide wider benefit to society</td>
<td>Lack of awareness</td>
</tr>
<tr>
<td>Increased worker health, productivity and creativity</td>
<td></td>
</tr>
<tr>
<td>Additional recreational opportunities for people and building occupants</td>
<td></td>
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<td>Source: Author</td>
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**Table I.** Drivers and barriers to wider use of green roofs

<table>
<thead>
<tr>
<th>Rank order</th>
<th>Year</th>
<th>Number of buildings constructed</th>
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</tr>
<tr>
<td>2</td>
<td>1990</td>
<td>19</td>
</tr>
<tr>
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<td>1972</td>
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<td>4</td>
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<td>14</td>
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<td>7</td>
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<td>8</td>
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<td>1969</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>1960</td>
<td>10</td>
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Source: Author

**Table II.** Rank order of year of construction

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<tr>
<th>Valid</th>
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<th>Per cent</th>
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<th>Cumulative per cent</th>
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<td>15.0</td>
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</tr>
<tr>
<td>No</td>
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<td>80.2</td>
<td>95.2</td>
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<td>4.8</td>
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</tr>
<tr>
<td>Total</td>
<td>521</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table III.** Green roof option

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<th>Missing</th>
<th>Frequency</th>
<th>Per cent</th>
<th>Cumulative per cent</th>
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<tbody>
<tr>
<td>System</td>
<td>5</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>526</td>
<td>100.0</td>
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</tbody>
</table>
Table IV Overshadowing of roofs

<table>
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<th>Frequency</th>
<th>Per cent</th>
<th>Valid per cent</th>
<th>Cumulative per cent</th>
</tr>
</thead>
<tbody>
<tr>
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<td>205</td>
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<td>39.3</td>
<td>39.3</td>
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<tr>
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<td>127</td>
<td>24.1</td>
<td>24.4</td>
<td>63.7</td>
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<tr>
<td>Partial</td>
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<td>35.9</td>
<td>36.3</td>
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<tr>
<td>Total</td>
<td>526</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References


University of Sheffield (2005), “Feasibility study for retrofitting of green roofs”, Sheffield.

Further Reading


Corresponding author

Sara J. Wilkinson can be contacted at: s.wilkinson@deakin.edu.au