Accelerated Development and Sustainability:
The Retrofit of Green Roofs in City Centres

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Keywords: green roofs, commercial buildings, sustainability, building adaptation, Australia.

ABSTRACT

Although it has a relatively low profile, one method of increasing sustainability in buildings currently being considered is the provision of green roofs. Most importantly, green roofs have thermal benefits in reducing heat loss and reducing heat gain and also enhancing bio-diversity. Furthermore, green roofs can absorb some of the carbon emissions in the CBD. With the increasing emphasis placed on climate change and much of the emphasis placed on new buildings only, it is accepted that Australia needs to increase the adaptation of the existing commercial building stock (CSIRO, 2002 AECOM 2008). At the same time the city of Melbourne has launched the 1,200 building program which aims to refurbish 1,200 CBD properties before 2020 as part of their policy to become a carbon neutral city by 2020.

This paper address the research question: *what is the potential of existing buildings in the CBD to accommodate a retrofitted green roof?* Furthermore *how many buildings are suitable for green roofs?* In the process of conducting the analysis this research examined 528 building surveyed in the Melbourne CBD in 2008 and 2009. The paper outlines the types of green roof which can be retrofitted to existing buildings. The outcomes of this research is applicable on a global basis and relevant to all urban centres where existing commercial buildings can become part of the solution to mitigate the impact climate change and enhance the city.

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1. INTRODUCTION

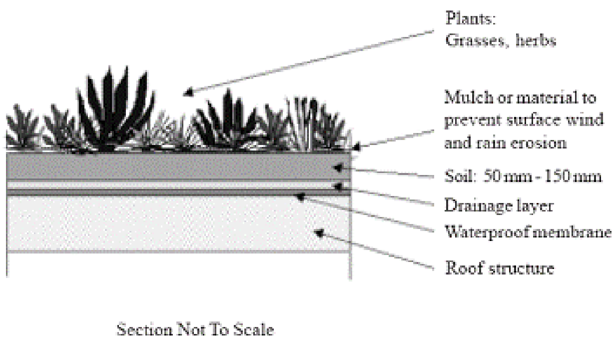
With the drive to increase sustainability of the existing building stock one of the options considered by building owners is whether to retrofit a green roof. CSIRO has stated that Australia needs to increase the adaptation of the existing commercial property stock to reduce building related greenhouse gas emissions (CSIRO, 2002). The City of Melbourne authority has taken this on board and has published plans for the city to become carbon neutral by 2020 (ARUP, 2008). A target of 1200 building adaptations has been established to deliver the 24% greenhouse gas reductions to be achieved through sustainability measures implemented to existing buildings. Some of these carbon emission reductions could be achieved through the provision of green roofs. Given that Germany had over 10 million square metres of green roofs in 1996; are we missing an opportunity in Australia?

2. TYPES OF GREEN ROOFS

Firstly, what is meant by the term 'green roof'? Green roofs can defined as roofing that uses plants which range from 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. Green roofs are a living vegetated roofing alternative to traditional impervious roofing materials.

Physically a green roof comprises the following components; a roof structure; a waterproof membrane or vapour control layer; insulation (if the building is heated or cooled); a root barrier to protect the membrane (made of gravel, impervious concrete, pvc, tpo, 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).

Figure 1: Typical roof section to illustrate the green roof components



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

Typically green roofs are split into two categories; intensive or extensive. Extensive green roofs are roof gardens which typically provide space for people. The depth of soil or substrate layer provided varies between 50 to 200mm and requires artificial irrigation. Intensive roofs often require a deeper planting medium greater than 150mm. Some authors refer to a third type; a semi intensive green roof which is a hybrid of the intensive and extensive roofs (Skyring, 2007).

A critical success factor is to keep the plants alive in the long term and this is a challenge as it requires an active and ongoing commitment to a maintenance and irrigation or watering regime (Skyring, 2007). Standard soils are not used because they are deemed to heavy for roof structures and a calculated ratio of aggregate (shale, vermiculite etc), 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 rainfall (as in the Northern Territories) or minimal rainfall (as in Victoria).

Table 1: Summary of characteristics of extensive and intensive green roofs

Extensive green roof	Intensive green roof
Shallow growing medium (<150mm)	Deeper growing medium (>150mm)
Lightweight structure to support roof	Heavier roof structure required to support roof
Cover large expanses of rooftop	Small trees and shrubs feature
Requires minimum maintenance	more maintenance required
Lower capital cost	More expensive
Not usually recreational	More common in tropical climates
Can be accessible or inaccessible	Can be accessible or inaccessible
Does not usually require irrigation	
Minimum structural implications for existing buildings	

Source: Author

3. BENEFITS OF GREEN ROOFS

There are many documented benefits of green roofs in the literature. One benefit is said to be the reduction of external noise for occupants, with the substrate and vegetation absorbing airborne noise (Skyring, 2007).

Water harvesting is possible from green roof systems. 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. This is limited in South Australia and Victoria where levels of rainfall are low and there has been a 10 year drought.

Stormwater management, some studies found that between 50-85% of stormwater volume is reduced. Furthermore the percolation and filtering of the stormwater improves the quality of stormwater entering the main drainages systems. In the Northern Territories and in northern Queensland high levels of rainfall occur during the 'wet' season each year.

Energy conservation of between 15 to 30% has been 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). Green roofs have been found to lower surface roof temperatures by 40-50 degrees Fahrenheit, 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 also lead to a reduction in the 'urban heat island effect' of city centres (Peck & Callaghan, 1999). The heat island is caused when the heat from the sun is absorbed into buildings by the roof and then released back intro the air leaving city centres a degree or two hotter than outer suburbs and rural areas.

For building owners seeking to promote sustainability and to offset the impact of obsolescence, and accreditation through the green rating tools, some such as the US designed LEED tool, does award points for green roofs and therein lays an additional benefit of adopting green roofs.

A further benefit 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 & 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. Other community or social benefits are considered to be increased worker health; productivity and creativity (Peck & Callaghan, 1999) though empirical studies directly establishing a causal link between worker productivity and the provision of a green roof do not exist yet.

On a practical level, green roofs 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. Furthermore financial savings are made 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 (Peck & Callaghan, 1999). In summary the benefits of green roof are found to be environmental, economic and social (see table 2 over).

Table 2: Summary of benefits of green roofs

Benefits of green roofs	
Environmental	Reduction of noise pollution Water harvesting Stormwater management Energy conservation and greenhouse gas emissions reductions Reduces heat island affect Pollution abatement
Economic	Credits available in known environmental rating tools Less maintenance required during roof life cycle Less energy consumed lowers bills New employment opportunities for a wide range of professionals including suppliers and manufacturers of green roofing materials
Social	High aesthetic values provide wider benefit to society Increased worker health, productivity and creativity Additional recreational opportunities for people and building occupants.

Source: Author

4. BARRIERS TO GREEN ROOFS

Given the number of benefits of green roof and the fact that the technology has been available for well over two decades; why are there not more green roofs to be found in our city centres? The barriers to green roof uptake is perceived to be a lack of awareness within the development industry, government officials and general public regarding the benefits of green roofs. Furthermore 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). For example in Basel, Switzerland planning policy requires all new flat roofs are green roofs and thereby presents a very pro-active approach to encouraging green roof technology.

Another barrier is perceived to be the nigher construction costs associated with new green roofs. Skyring (2007) estimated costs are double those of 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 & Callaghan, 1999).

There are also barriers in adopting new methods and techniques in property and construction. There is no long term experience of green roof technology on which to draw. 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 confidence is experienced within the sector about green roofs.

Finally a major issue is related to the technical data limitations in calculating the benefits of green roofs. As noted above the range of benefits achieved through the installation of green roofs is varied by the buildings location, climate and construction type. Therefore the advertised savings may not be fully achieved in practice and this may deter some from adopting the measure.

5. BUILDING ATTRIBUTES FOR GREEN ROOFS

The suitability of a roof for a green roof is dependent on the roof type, size and slope. Extensive and intensive roofs require a minimum slope of 2% and roofs with less than 2% slope require additional drainage measures to avoid water logging (University of Florida, 2008). Additional requirements are good drainage, lightweight growth media, waterproofing, additional structural support, rainwater harvesting and the use of drought / heat tolerant plants. Longevity of the structure, drainage and waterproofing system is essential because the cost of replacement is high. Green roofs are designed to last a minimum of 50 years which is twice the life cycle of a roof covering such as bituminous felt for example. Overall the following criteria are taken into account when determining whether a roof is suitable for retrofitting with a green roof.

1. Position of the building
2. Location of the building
3. Orientation of the roof
4. Height above ground
5. Roof pitch
6. Weight limitations of the building
7. Preferred planting
8. Sustainability of components
9. Levels of maintenance.

The first six criteria are purely physical attributes of buildings. Criteria 7 to 9 are related to building owner and or client desires and the ability to maintain green roofs.

6. OTHER FACTORS TO CONSIDER IN DECISION MAKING

In addition to the building related criteria other factors will influence the potential to retrofit a green roof to an existing building. 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. For example in the north there is high rainfall during certain months of the year, whereas in the south and south-eastern part of Australia prolonged periods of drought are not uncommon. Green roofs in these locations would require very different planting regimes and have different needs regarding watering and maintenance.

Owners and or facility managers need to consider maintenance requirements. Long term maintenance is essential and a minimum 5 year maintenance contract is recommended initially to ensure the correct processes are undertaken and than the planting gets properly established.

Finally there is the budget to consider; 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 cost.

7. RESEARCH QUESTIONS, AIMS AND OBJECTIVES

This research adopted a very simple research question; what is the extent of the potential to retrofit green roofs within the city of Melbourne central business district (CBD)? The aim was to examine the whole CBD building stock to identify the number of buildings which contained the attributes or characteristics required for green roof adaptation. Melbourne is fairly representative of a major city in a developed country. Similar development patterns are found in other Australian city centres such as Sydney and, to a lesser extent, in Perth and Brisbane. Furthermore Melbourne is considered to contain similar buildings to other global cities in the US and elsewhere.

8. RESEARCH METHODOLOGY

The research method developed utilised a building database which has been compiled by the author over several months of the Melbourne CBD. The database has been complied using a number of sources such as existing commercial databases such as Cityscope, and publicly available databases such as PRISM and the Heritage database. In addition data from the Property Council of Australia (PCA), Google Maps, Google Earth and Google Street View was used by the researcher to gather building related data. Finally the research also made visual inspections and took photographs of the CBD buildings. The building database contains 521 commercial buildings in Melbourne CBD.

The following criteria are taken into account when determining whether a roof is suitable for retrofitting with a green roof.

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8. Sustainability of components
9. Levels of maintenance.

In this research all the 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.

In the database the researcher had to determine whether a green roof was an option or not or possibly an option. Using the Google Map 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 on nearby planting, whether the building was overshadowed partially, completely or not at all. The compilation of this unique database enables the researcher to evaluate, for the first time on such a large scale the potential for retrofitting existing buildings in the CBD with green roof technology. The database was complied in an excel format and then transferred for analysis into SPSS version 17. The results of this research will enable 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 also allow other municipal authorities to reflect on the potential of their stock to accommodate such a retrofitting programme.

9. DATA ANALYSIS

This first section provides an overview of the CBD stock in December 2008. The age of the buildings have been profiled and reveal that the stock is ageing with an average age of 61 years or built in 1944. The oldest building was built in 1853 and the most recent in 2005, note that new buildings have been completed since 2005 but are not in the database information. The top ten years for the construction of new buildings are recorded in Table 3 below. Only two entries are pre war, and this is reflective of considerable post war construction in the CBD. Since 1940 302 (or 60.4%) new buildings have been added in the database population.

Table 3 – Rank order of Year of construction

Rank order	Year	Number of buildings constructed
1	1945	38
2	1990	19
3	1972	15
4	1991	14
4	1930	14
4	1920	14
7	1973	12
8	1987	10
8	1969	10
8	1960	10

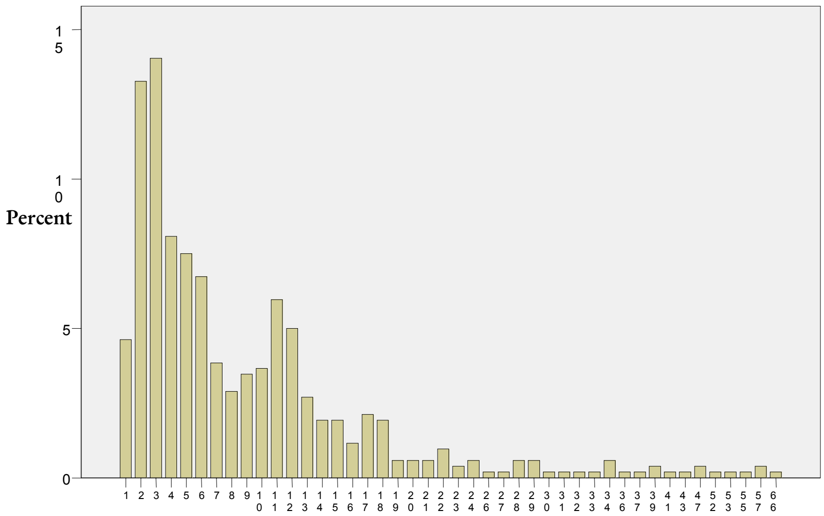
Source: Author

There is a consensus that minor adaptations are required within a 5-7 year period after construction, with major works being carried out between 20-25 years when services require replacement. Given the high number of new buildings constructed from the 1960s onwards (237 number) there is a large amount of potential stock which would be due for updating and adaptation and consideration of retrofitting green roofs.

When we consider building height, which is an issue in green roof technology, the modal number of stories is three and therefore most buildings are low rise, and partially or totally overshadowed in some cases. 405 of the stock is four stories or less and 68.1% are 10 stories or less. 4.4% of the stock is between 21 and 30 stories in height and 2% are 31 to 40 stories high, 0.8% is 41-50 stories high and 0.2% is up to 66 stories high.

Figure 2 shows the numbers of storey in all the buildings and reveals that most are classed as low to medium rise. A definition of what is a high rise building is very general and refers to metres in height rather than number of stories. In Australia the Property Council of Australia has an office building quality matrix which classes buildings from premium (the best) through A, B, C and D grades (the lowest) – part of the grading criteria is Net Lettable Area (NLA) and not number of stories (PCA, 2006). According to some definitions buildings over approximately 7 stories (or 23 metres high) are in the high rise class and those over 80 metres or approximately 20 stories are deemed skyscrapers. Figure 2 shows that a significant minority of all building are within high or sky-rise heights which cast shadows over adjoining lower buildings as the sun moves across the sky during the daytime. Such an arrangement of buildings could mean that existing properties which have adequate structural strength to accommodate retrofitting with green roofs may be unsuitable because of overshadowing which would adversely affect planting.

Figure 2 - Number of storey's in buildings

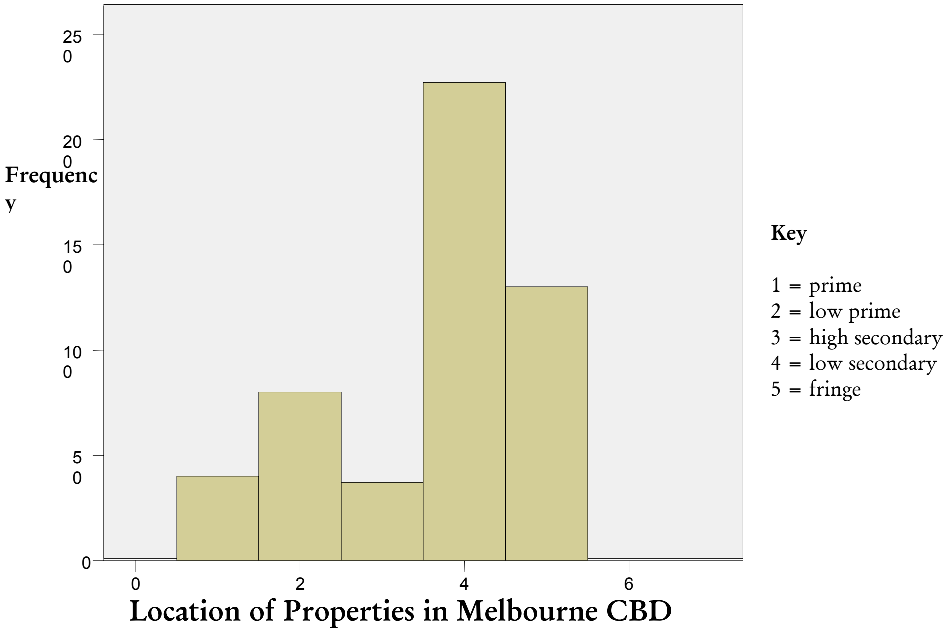


Number of storeys in Melbourne CBD buildings

10. SITE AND LOCATION

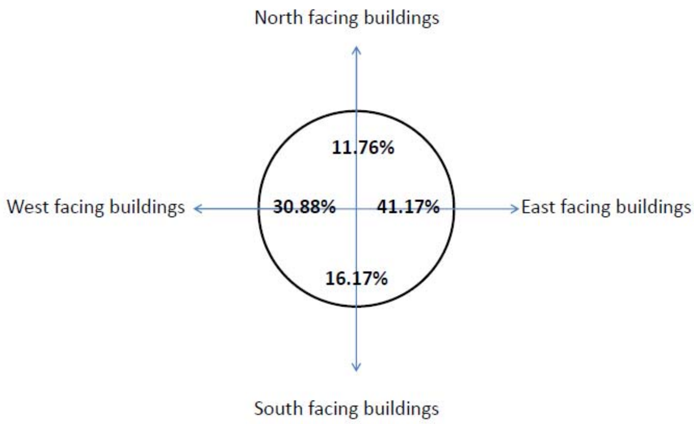
Authors have noted the significance of the site and the location of the building with regards to building adaptation (Kincaid, 2002). Within the Melbourne CBD, locations are categorized as 'prime' (the best location), 'low prime', 'high secondary', 'secondary' and the lowest grade ‘fringe. The sample contained 526 buildings and revealed that 7.6% were located in the prime zone, 15.2% in the low prime area, and 7% in the high secondary area – thus 29.8% of all properties were located in the higher grade location zones. The highest number or 43.2% were is in the low secondary area and nearly a quarter (24.7%) in the fringe area at the periphery of the CBD grid. Figure 3 below illustrates the distribution of the database properties within the five CBD zones.

Figure 3 - Building location (*source: Author)*



Other aspects of the site are orientation, which determines how much exposure to sunlight the roof gets, and site boundaries. Site orientation revealed that most buildings in the sample of 72 were facing east (41.17%) followed by west facing buildings (30.88%), then south facing properties (16.17%) and finally north facing buildings comprised 11.76% of the sample. In the southern hemisphere north facing properties will be exposed most to the direct sun. Therefore it appears that a large number of buildings will only have partial exposure to sunlight during the course of any day, even before overshadowing is considered.

Figure 4 - Building orientation in Melbourne CBD (*source: Author)*



Research conducted by Povell & Eley (in Markus, 1979) and Isaacs (in Baird et al, 1996) noted that the number of site boundaries (that is whether a building is adjoined to another or others) determines the ease of adaptation. Those which are not attached to other buildings tended to be easier to adapt because of access to all sides of the property and the lack of disturbance caused to neighbours. This sample of 521 properties were mostly (47.4%) bounded on two sides. 21.9% were bounded on one side only and 18% were bounded on three sides. Only 12.1% were bounded on no sides by any properties (or free standing). Overall then most properties in the sample are not affected adversely by attachment to other buildings or restricted access for construction works, which is good for retrofitting activity.

11. STRUCTURE

60.6 percent of the buildings 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% are of traditional load bearing brickwork and / or stone construction. The buildings with concrete frames are more likely to be suitable for retrofitting with extensive green roof systems and this analysis reveals good potential for minimal structural changes to most CBD buildings. Note 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. Clearly there is not sufficient time or financial resources to undertake structural appraisal of all buildings in this research. The remaining building criteria of preferred planting, sustainability of components and levels of maintenance were not considered in this research and therefore represent some of the limitations of this approach.

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12. GREEN ROOF POTENTIAL

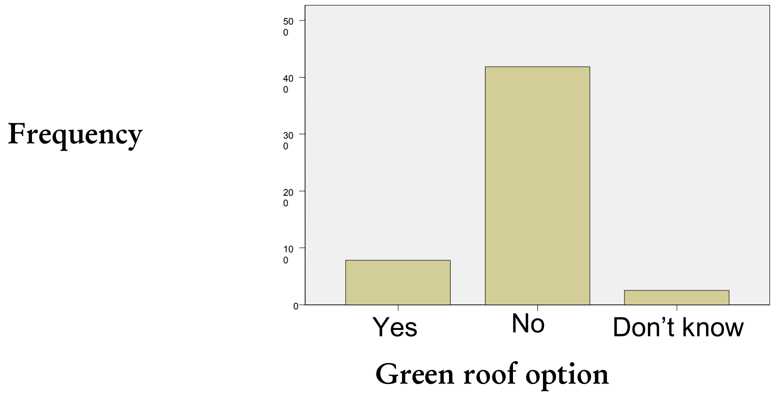
The next stage of the research involved a visual inspection of the roof using the Google Earth, Google Map and Google Street View softwares whereby it is possible to zoom in and out of rooftops on buildings. The primary researcher is a chartered building surveyor with 22 years post qualification experience. An evaluation of the potential of each roof for retrofitting with green roof technology was undertaken. The evaluations called for a classification of either 'yes', 'no' or 'don't know' for retrofitting. The evaluation was based on roof pitch i.e. those pitched above 30 degrees and below 2% were deemed unsuitable. The amount of roof top plant especially equipment which vents air from the building was also taken in to consideration. Also the provision of rooftop window cleaning equipment was considered, and where coverage of rooftop plant and other equipment exceeded 40% of roof area the roof was deemed unsuitable for retrofit. Another criterion was roof construction, lightweight construction covered with corrugated roofing was deemed unsuitable.

The results shown in Table 4 and figure 5 show that only 15% of the building were considered to be suitable for retrofit with green roof technology. A minimal 4.8% were not classed with yes or no, and a significant percentage of 80.2% were not considered suitable for retrofit based on the criteria above.

Table 4 Green roof option (*Source: Author*)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	78	14.8	15.0	15.0
	no	418	79.5	80.2	95.2
	Don't know	25	4.8	4.8	100.0
	Total	521	99.0	100.0	
Missing	System	5	1.0		
Total		526	100.0		

Figure 5: Green roof option



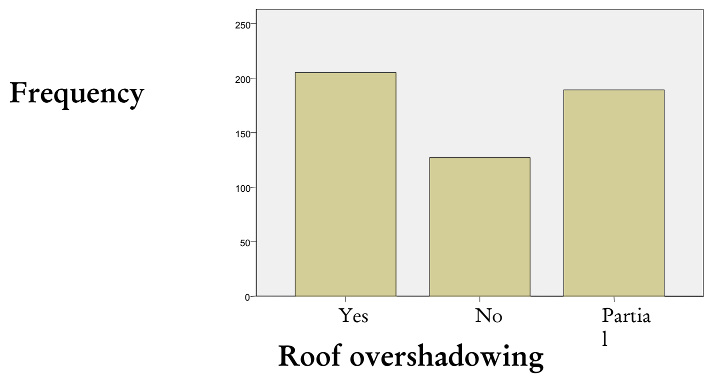
(*Source: Author*)

The final stage involved an analysis of overshadowing of the stock (see Table 5). Orientation and proximity of other taller buildings was also taken into account. The analysis revealed that 39.3% were overshadowed and 36.3% were partially overshadowed. Only 24.4% were not overshadowed at all. Therefore three quarters of the existing stock is considered unsuitable for green roof retrofit on the basis that insufficient sunlight reaches the rooftop for planting to flourish. Furthermore in Melbourne there has been an ongoing drought for over 10 years and the extremely low levels of precipitation make growing vegetation on green roofs challenging. It is considered more water would be drawn out of the mains water system to maintain planting thereby further diminishing already low water 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 options place a further cost burden on owners.

Table 5 Overshadowing of roof

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	205	39.0	39.3	39.3
	no	127	24.1	24.4	63.7
	partial	189	35.9	36.3	100.0
	Total	521	99.0	100.0	
Missing	System	5	1.0		
Total		526	100.0		

Figure 6: Roof overshadowing



13. BI-VARIATE ANALYSIS OF GREEN ROOF CRITERIA

The following section reveals some of the bi-variate analysis of building attributes and green roof criteria to establish which buildings were most likely to support green roofs in the CBD. Figure 7 below 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 7 Green roof option and location of buildings
(source: Author)

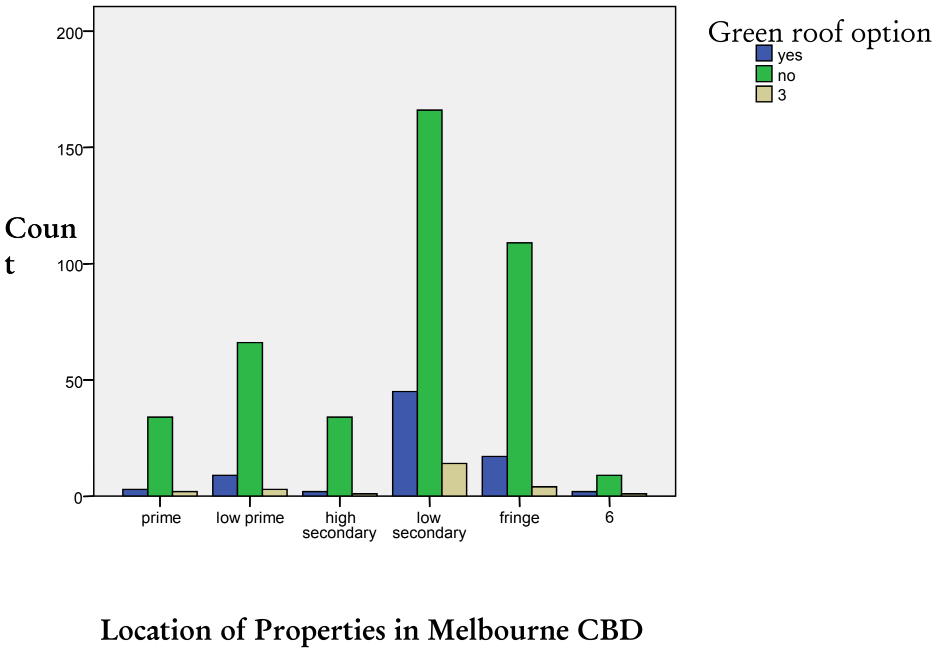


Figure 8 Green roof option and historic listing status
(source: Author)

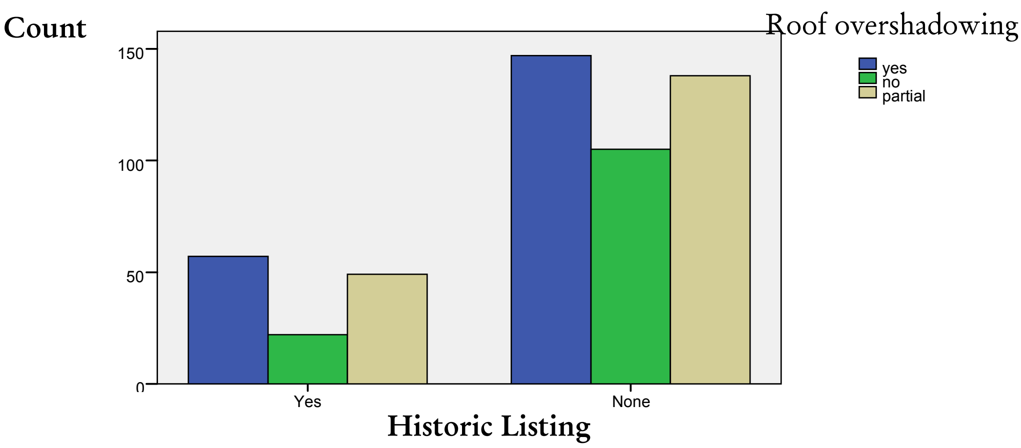


Figure 8 shows that a significant minority of buildings in the population have historic listings which mean that all proposed alterations have to comply with strict heritage guidelines and therefore this portion of the stock, regardless of whether it is physically suitable for green roof retrofit will be eliminated from consideration. Of the non listed stock less than a third is overshadowed and has reasonable exposure for a green roof retrofit. Over a third has partial overshadowing and with more detailed analysis some of this group may have sufficient sunlight exposure to support green roof vegetation.

Figure 9 Roof overshadowing and PCA grade
(source Author)

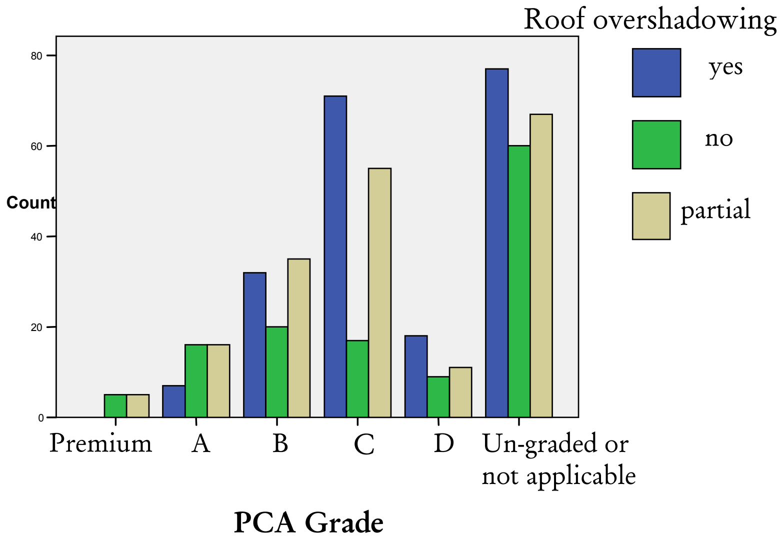


Figure 9 shows the relationships between roof overshadowing and PCA office quality grade. Most buildings in the population are ungraded and therefore could have a low quality of construction and maintenance. Of the graded buildings, the most suitable groups are found the B grade stock, followed by the C, then A, then D and finally Premium stock. This is because premium stock with their high demands for plant and services tend to use rooftops for plant and equipment. The Premium, A and B stock is most likely to be owned by institutional investors and larger organisations who are more likely to have adopted CSR and consequently are considered more likely to pursue green retrofit than the private individuals who own the bulk of the C and D grade 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.

Figure 10 Roof over shadowing and construction type.
(Source Author)

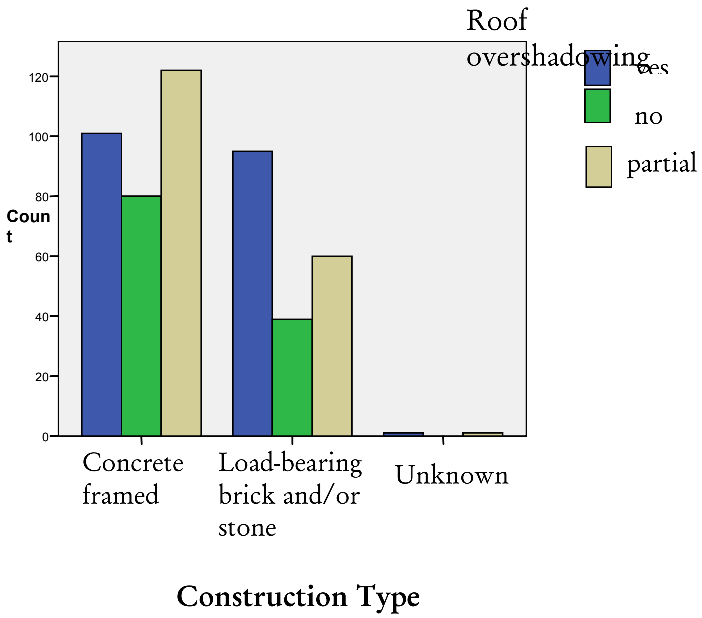
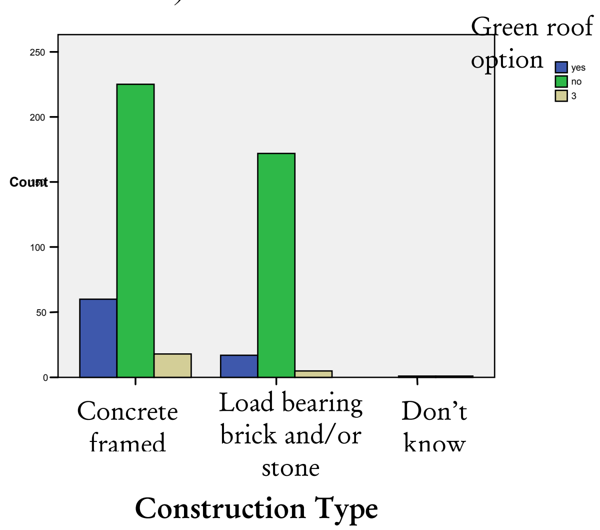


Figure 11 Green roof option and construction type
(source: Author)

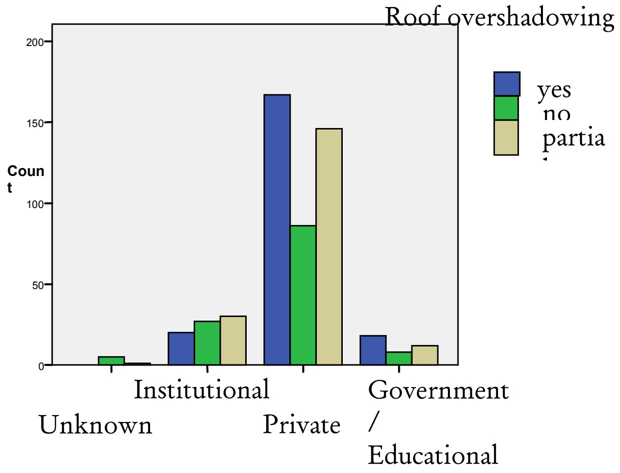


When construction type and roof overshadowing and green roof option are correlated, (see figures 10 and 11) it is apparent that concrete properties are more suited to green roof adaptations because they require minimum structural alterations to accommodate the additional weight of the roof system (University of Florida, 2008).

Figure 12 below shows that when building ownership is taken in to account and correlated with overshadowing, overall most stock is privately owned in the CBD and therefore policymakers will be challenged to target appropriate incentives this disparate group of owners (Peck & Callaghan, 1999). 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 budgets permitting 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. 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 / educational sector stock a similar profile exists albeit to a much smaller quantity of buildings.

Figure 12 Roof overshadowing and ownership
(source Author)



14. FINDINGS

Six key findings are noted in relation to the potential to retrofit green roofs in the Melbourne CBD.

1. Only 15% of the 526 buildings in the database were considered physically suitable for retrofitting with green roof technology
2. Only 3.1% of roofs have a north facing orientation, are not overshadowed and are considered 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

15. CONCLUSIONS AND RECOMMENDATIONS

Social, economic and environmental arguments for 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.

The limitations which affected this research are as follows; three of the nine criteria for green roofs were not considered in the project. These criteria were; preferred planting, sustainability of components and levels of maintenance. They were considered outside the scope of this research which 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.

Over 521 buildings were analysed only 78 appear to be suitable for green roof technology, therefore the conclusion is that there is very limited potential for green roof retrofit on a wide scale in Melbourne. 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 very high number of CBD buildings and also the thorough expert lead visual inspections of each building in the database. The research aim has been achieved and building attributes of location, height, construction (weight limitation), building grade, roof orientation, roof pitch, proximity of roof plant and equipment and amount of overshadowing from adjoining stock have been thoroughly considered in the analysis of green roof potential.

It is suggested that a similar analysis of a regional Victorian city is undertaken to establish whether more potential exists there than in the high density inner city of a State capital. In this way policy makers will know whether strategies to encourage green roof adaptation are better suited to suburban and regional urban centres more so than the inner city.

REFERENCES

ARUP (2008). existing buildings / survival strategies. A toolbox for re-energising tired assets. PCA, Property Council of Australia**:** 67.

Kincaid, D. (2002). Adapting buildings for changing uses. Guidelines for Change of Use Refurbishment, Spon Press.

Naichou, A., Papakonstantinou, K., Sanamouris, M., Tsangrassoulis, A., Mihalakakou, G. 2001. *Analysis of the green roof thermal properties and investigation of its energy performance.* Energy and Buildings. Vol. 33. Pp 719-729.

PCA, 2006. A guide to office building quality. Property Council of Australia Limited. ISBN 1 876748 23 0.

Peck, S.W. & Callahan, C., 1999. Greenbacks from green roofs: Forging a New Industry in Canada. Final report. March 1999.

Povell & Eley, in Markus, 1979.

Skyring, S., 2007. Green Roofs for Australia Conference. Brisbane. 22nd – 23rd February 2007. www.agdf.org.au

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