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Sustainable Urban Retrofit Evaluation

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Sustainable Urban Retrofit Evaluation

Report for Royal Institution of Chartered Surveyors

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A report for Royal Institution of Chartered Surveyors

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Executive Summary

Background

Adaptation of the existing building stock is an essential component in man-kinds attempts to mitigate the effects of global warming. Significantly most of the global stock was constructed with no consideration of sustainability. In the UK 87% of the residential stock that will be around in 2050 is already built (Kelly, 2008). In Australia environmental sustainability for commercial buildings was legislated in the Building Code of Australia as recently as 2006, with minimum standards for energy efficiency applied to new build and some retrofit projects. Therefore the majority of Australian stock has been designed with little or no consideration of energy efficiency. In 2008 the City of Melbourne launched the 1200 Buildings Program as a key strategy to deliver carbon neutrality by 2020 after Arup (2008) had concluded that 1200 office building retrofits would deliver a 38% reduction in greenhouse gas emissions. Given these circumstances it is likely that the scope and extent of retrofit will increase over time as Melbourne, and other global cities strive to become carbon neutral.

In retrofit multiple attributes are important and they can be labelled as economic, location and land use, physical, legal, social and environmental attributes. Ultimately, it is argued that although costs can be traded against social and environmental gains, retrofit has to be economically sustainable. A study examining 7393 retrofits from 1998 to 2008 in Melbourne Central Business District (CBD) found that no environmental attributes were important in retrofit (Wilkinson, 2011). However given recent legislation and a greater drive for sustainability, the question is; which attributes are of most importance in office building retrofit; and is this changing over time?

Purpose and scope

This research updates the Wilkinson study (2011), with part one examining whether there has been a shift in the Melbourne market by assessing the importance of environmental attributes in commercial office retrofits from January 2009 to July 2011. The second part of the study had two aims; firstly, to gain a deeper understanding of the improvements made to existing office buildings in the 1200 Buildings Program in Melbourne, Australia. The second aim was to undertake a comparison of current practice to identify similarities and differences in approach to retrofit in the 1200 Buildings Program.

The study

Decision making regarding building retrofit is multifaceted and many found the ranking of attributes influencing retrofit subjective. This study used a database of retrofits and attributes to determine important attributes with the advantage that a large number of retrofits can be studied and secondly; it was not subjective. Using the criteria identified as important in previous studies, a database was designed and assembled. The sources for the database included the Building Commission of Victoria Building Permit and 'Cityscope' databases, whilst commercial data from the Property Council of Australia and visual inspections completed the database. The variables above were coded as physical, social, legal, economic and environmental. The research examined all retrofits in a mature commercial market and the Melbourne CBD in the original street grid set out by Hoddle; a distinct geographical location occupied since 1834.

Part one adopted Principal Component Analysis (PCA); a technique of weighting dimensions in cross sectional data having the ability to reveal, untangle and sum up configurations of connection (Horvath, 1994). From original variables PCA reduces data into a smaller set of new merged components with the least loss of information (Hair et al., 1995). Some 42 variables were input into the PCA to generate a lesser number of components. The attributes comprised social, economic, environmental, legal and physical attributes identified in previous studies as being important in retrofit. Different levels of works were classified as minor works, alterations, change of use, alteration and extensions, new build and demolition. This research examined alterations works which are minor in nature for example, the retrofit of a number of floors rather than the entire building.

Part two examined current practice regarding sustainable commercial retrofit as practised by participants of the 1200 Buildings Program. Aim two was to compare current practice to identify similarities and differences in approach to retrofit and the introduction of sustainability measures. The City of Melbourne provides case study exemplars of the buildings within the 1200 Building Program on its website[1]. All the cases posted on the official City of Melbourne 1200 Buildings Programme website in September 2012 were used in the analysis. There were ten projects in total.

1 http://www.melbourne.vic.gov.au/1200buildings/CaseStudies/Pages/CaseStudies.aspx

Table 1 Summary of the PCA for alterations retrofits

Component number	Component name	Component attributes
1	Environmental and physical (32%)	Property Council of Australia building quality grade (29%) NABERS rating (26%) Aesthetics (25%) Height (number of storeys) (20%)
2	Social and physical (15%)	Historic listing (42%) Construction type (29%) Parking (28%)
3	Physical (14%)	Street frontage (60%) Vertical services location (40%)
4	Environmental (10%)	Green Star rating (100%)

Key Findings

1275 alterations retrofits were analysed in the study. Four components of attributes had the highest importance on retrofits explaining 71% of the original variance (see table 1). The attributes were vertical services location, number of storeys, PCA grade, National Australian Built Environment Rating System (NABERS) rating, type of construction, Green Star rating, parking, historic listing, street frontage and aesthetics.

In component one Property Council of Australia building quality grade, NABERS rating, aesthetics and number of stories are highly or very highly loaded on component 1 (table 1). These variables explain 32% of the original variance and the first three relate to sustainability (environmental and social) and the fourth to height (physical); and collectively these attributes are labelled 'environmental and physical'. Aesthetics relates to appearance indicating that buildings of poor appearance are less likely to be adapted. The 'number of stories' is strongly and negatively loaded and relates to physical dimensions of the building.

Three attributes loaded high on component two; historic listing, construction type and parking and explained 15% of the variance. In component two attributes were influenced by social and physical components. Historic listing applies to the social values or characteristics. Construction type and the provision of parking relates to physical attributes. Historic listing limits to some degree the level of work which any owner or user can undertake.

In component three, street frontage (building width) and vertical services location are very strongly and moderately loaded, explaining 14% of the variance (table 1). The attributes are physical and relate to the size and dimensions of the building and flexibility in terms of space configuration. One attribute Green Star rating is very strongly loaded on component four and explained 10% of the variance (table 1). The attribute measures the provision of an environmental rating for a floor or a building and is described as environmental.

Overall with the PCA, two environmental attributes, NABERS and Green Star are important in building retrofit at a minor level; this is a major change from the earlier study (Wilkinson and James, 2011). Previous studies simplified the groupings of attributes based on logic rather than a quantitative process, the PCA overcomes this and is based on a large sample. Physical attributes featured in three of the four components and shows that the physical attributes remain important although other social and environmental attributes are included.

In part two 70 measures were implemented across the ten case study buildings. These measures can be categorised as economic, environmental and social. Many of the environmental measures were implemented because of the potential economic benefits; either reduced operational costs and/or, enhanced market value.

Unsurprisingly, 61% of measures related to the building services. 73% related to energy efficiency reflecting the importance of energy efficiency in sustainability particularly in the attainment of NABERS and Green Star ratings. It is indicative of existing energy performance levels of existing stock.

Measures to the building fabric were associated with energy efficiency. Opportunities for building fabric measures occur less frequently, involve access challenges and disruption to occupants, as well as being expensive. However once undertaken these measures offer a more long term solution than upgraded services which require maintenance and will be replaced typically within a 20 year period.

Water economy measures featured less frequently. The reasons could be that water economy is not as important as energy, or more likely, that due to stringent water restrictions imposed during the 10 year drought in the early 2000s many Melbourne buildings operate reasonably efficiently in terms of water.

Social sustainability was mentioned in four cases in respect of amenities provided to users in respect of improved internal environmental quality (IEQ). One project featured a roof top garden which provided a pleasant social space, however the rationale for inclusion also included environmental benefits of reducing the heat island effect, insulating the roof and reducing energy use (an economic benefit). Finally one project featured a building which housed small businesses which were driven by social justice and equity issues; thereby having a positive social sustainability contribution. Overall social sustainability has a lower profile within the retrofits. Table 2 below summarises the case studies and their social, economic and environmental aspects.

Table 2 Case Study summaries of sustainability aspects

Case study	Economic	Environmental	Social
131 Queen Street	X	X	X
636 Bourke Street		X	X
247 Flinders Lane		X	X
490 Spencer Street	X	X	
500 Collins Street		X	
406 Collins Street		X	
182 Capel Street		X	X
115 Batman Street	X	X	X
385 Bourke Street		X	
530 Collins Street		X	

Conclusion

Alterations retrofits comprised the highest number of events, indicating that Melbourne office building owners engaged most in this level of retrofit from January 2009 to July 2011. Although it covered the period immediately following the Global Financial Crisis of 2008, around 46 events occurred each month. Commercial building retrofits accounted for 55% of all work in the CBD, followed by retail at 29%, therefore the City of Melbourne are targeting the most active sector and has the potential to deliver the highest level of emissions reductions.

For part one, the research questions were; (a) are environmental attributes important in office retrofit? and; (b) where is the sustainable office retrofit market trending? This study shows that environmental attributes were important in alterations retrofits in the Melbourne CBD between January 2009 and July 2011. The NABERS tool accounted for 26% of the importance in component one. In component four, the environmental attribute Green Star accounted for 100% of importance. The second question asked where practices in respect of sustainable retrofit of offices is trending and, on the basis of this study, it appears that there is a positive impact of the energy efficiency provisions of the Building Code of Australia and the introduction of the Mandatory Disclosure legislation of 2010. It is likely this impact will continue as leases expire over the next four years and as opportunities for sustainable retrofits present themselves to owners.

In part two, the case studies revealed that the current practices in sustainable retrofit were;

- 61%, building services measures.
- 73% energy efficiency measures.
- 11% water economy measures.
- 17% building fabric measures.
- 6% social sustainability measures.

The second aim was to evaluate practice to retrofit in the 1200 Buildings Program compared to the 1998 to 2008 study of office retrofit in the CBD and the findings are as follows;

1. Owners are motivated by different drivers, and the predominant initiating parties were built environment consultants seeking to develop knowledge and experience in sustainable retrofit whilst upgrading their offices.
2. Fringe locations feature more prominently in the cases, however low prime is where most retrofits occur.
3. Aesthetics is important with 60% ranked attractive.
4. A wider range of land uses are drawn into retrofit than previously.
5. Buildings with smaller floor areas are more likely to be retrofitted.
6. Building widths were mostly in the lower range (up to 50 metres wide).
7. There is a preference for non-heritage buildings.
8. Higher retrofit rates occurred in low to medium rise stock.
9. Ungraded buildings were most likely to be worked on (50%), followed by B grade stock (20%).
10. Buildings were either detached (50% of cases) or attached on three sides (50% of cases).
11. Half of all retrofits have ‘good’ to ‘very good’ site access.

Clearly Melbourne’s carbon neutral policy is ambitious and ahead of its time. The results show environmental attributes have become more important in retrofit and the legislation is having the desired impact. Overall the retrofit focus is currently on energy efficiency measures and the majority of these measures are manifested through changes to building services. Substantial improvements have been afforded to buildings within the program in terms of energy efficiency, though higher take up rates are required to deliver the overall target.

1.0 Introduction

1.1 Rationale and background for the study

With acceptance of the relationship between energy consumption, greenhouse gas emissions and climate change, the built environment is a sector with high potential to lessen overall emissions (Dolan et al., 2010). Cities account for 75% of global energy consumption and 80% of greenhouse gas emissions (United Nations, 2007). Given that the built environment emits around half of all greenhouse gas emissions; it could play a significant role in mitigating global warming. The commercial office sector in Australia is responsible for 12% of all greenhouse gas emissions. It is a figure that is likely to be higher in countries with a predominance of service industries such as the UK. With around 2% of new buildings added to the total stock each year; the scope for emissions reductions lay with retrofit of existing buildings. This study focuses on activity in the commercial office sector in Melbourne, Australia.

In recognition of the contribution cities make to global warming; many cities aspire to be carbon neutral within a specific timeframe (Bulkeley et al., 2010). It is the case that the 'challenge of achieving sustainable development in the 21st century will be won or lost in the worlds urban areas' (Newton and Bai, 2008, p.4). The city of Melbourne in Australia is leading the way with a carbon neutral strategy for 2020, however many cities currently lack such systems (OECD, 2009). The city of Melbourne perceives that low carbon cities will experience enhanced future economic competitiveness (Pinnegar et al., 2008). Globally some other cities are engaging in low carbon strategies, in the UK, London and the City of Nottingham has a 'Low Carbon Transition Plan' as does San Francisco and New York in the USA (Gearty, 2007; DECC, 2009). Tokyo in Japan has a 10 year project for a carbon minus city dating from 2007 (City of Melbourne, 2008). This research is timely, with Dixon (2009) exploring transitioning to low carbon cities at a city level, this research focuses on one city, Melbourne and the progress to date of the 1200 Buildings Program in terms of sustainable retrofit activity in the CBD.

The main programme aimed at reducing building related greenhouse gas emissions by 38% before 2020 is called the '1200 Buildings Program' which was launched in 2008. Commercial building owners are actively encouraged to engage in sustainable retrofits to meet the policy target and the program has triggered an increased rate of retrofit and a wider engagement in the market. However how much has the rate of retrofit activity increased as a result of the 1200 Buildings Program? The implications of this research have significant ramifications for the increasing number of cities and towns globally embarking on similar low carbon transition policies (Kelly, 2009).

Successful retrofit demands that social, technological, economic and legislative criteria are addressed as well as environmental criteria (Wilkinson et al., 2009a). Furthermore retrofitted buildings have to meet user requirements and broader community needs (Langston et al., 2007; Langston, 2010). Melbourne, like most urban centres, comprises a range of different types of office stock with regards to age, size, location, height, tenure and quality. All buildings present challenges and opportunities with regards to retrofit and sustainability and integrating retrofit measures that reduce energy, water and resource consumption, enhance occupant health and well-being and have reduced environmental impact on habitat and biodiversity.

Whist there is a great opportunity that a wide scale programme of office retrofit will lead to overall environmental enhancement of the quality of the stock, there is a danger that a rapid program of retrofit will result in mistakes that may be embedded on the stock for many years to come (Langston et al., 2011). Furthermore recent research has concluded that environmental criteria have not proven to be important in retrofit decision making during the period 1998 to 2008 in the Melbourne CBD (Wilkinson, 2011; Wilkinson & Remøy, 2011). The study examined 7393 retrofit events' using a principal component analysis to identify the property attributes most important in office building retrofits. The results showed that levels of energy and water consumption were not important but that physical and size attributes, land and location attributes and amenity and social attributes were of great magnitude.

The research approach is proven in use (Wilkinson 2011, Wilkinson and Remøy, 2011) however the dates covered by the study stopped short of the period when sustainable retrofit began to be favoured in the market place. Sustainability was mandated in the Building Code of Australia in 2006 with energy efficiency measures. These requirements have been progressively extended since this date, most recently in 2010. In addition Building Energy Efficiency Disclosure Bill 2010 requires the mandatory disclosure of energy consumption in commercial buildings at the point of sale or lease from November 2010 in Australia (Warren, 2011). Under the legislation, sellers or lessors of office space of 2,000 square metres or more are now required to obtain and disclose an up-to-date energy efficiency rating or Building Energy Efficiency Certificate (BEEC). Building owners are required to address issues relating to energy consumption in their buildings as the market place becomes increasingly energy conscious. Non-compliance can lead to court order payment of a civil penalty of up to AUS$110,000 (approx £68,200) for the first day of non-disclosure. Furthermore the Department for Climate Change can issue infringement notices. A non-disclosure register listing people who commit two or more offences in 12 months has been established. Finally the Department of Climate Change will monitor advertisements and transactions to ensure BEECS are provided (Department of Climate Change, 2011). In February 2011, Prime Minister Gillard announced a carbon tax for Australia which commenced in July 2012. The carbon tax is another major change in the economy which focuses attention on energy use and energy costs.

1.2 Research Aims

As well as the changing Federal policy environment, there is evidence that the market has moved on since 2008 and this research has the following aims;

a to establish whether environmental attributes are important in office retrofit in the Melbourne CBD,

b to ascertain where the sustainable office retrofit market is trending in terms of the number and scope of adaptations since 2008 to the present day,

c To gain a deeper understanding of the improvements made to existing office buildings in the 1200 Buildings Program in Melbourne, Australia.

d To undertake a comparison of current practice to identify similarities and differences in approach to retrofit in the 1200 Buildings Program.

The stakeholders for the purposes of this research are building owners (private individuals and institutional investors), practitioners and consultants advising on retrofit (project managers, construction economists, architects, services engineers, contractors, leasing agents and valuers), regulators (planners and building control), building users and occupiers.

1.3 Structure of the report

This research comprises two distinct phases which are as follows;

1 An analysis of multiple property attributes to determine which are most important in retrofit using a Principal Component Analysis (PCA), and;

2 Presentation of illustrative case studies to demonstrate the 1200 Buildings Program in action.

Each phase adopts a different research technique and in the interests of clarity and simplicity each phase is reported in its entirety before moving on to the next phase. For each phase, the methodological issues, research method and data collection techniques are explained prior to a presentation of the results and a discussion of the findings. Any limitations of the methodology are also highlighted.

A final concluding section identifies the overall conclusions, highlights the key findings from the research project and identifies areas of further investigation.

2.0 The Literature

Background

The review is set out in three parts. Firstly the Zero Net Emissions policy of the city of Melbourne is explained with a focus on the aspects related to existing commercial office buildings; the focus of this research. A second section outlines the typical measures undertaken to retrofit commercial buildings in respect of enhancing sustainability which are the subject of the illustrative case studies in phase three. A third section outlines the property attributes considered in decisions about the retrofitting of commercial office buildings and which feature in the analysis undertaken in phase one. The final section identifies the different stakeholders and their respective roles which are explored in the analysis of phase two.

2.1 Zero net emissions

In 2002 the City of Melbourne commissioned a report which set out their strategy to become a carbon neutral city by 2020 (City of Melbourne, 2003). The three key strands of the strategy were

a) **leading edge design** of buildings to deliver a reduction of 50% of the greenhouse gas emissions (or 1,850,000 tonnes) from City of Melbourne buildings,

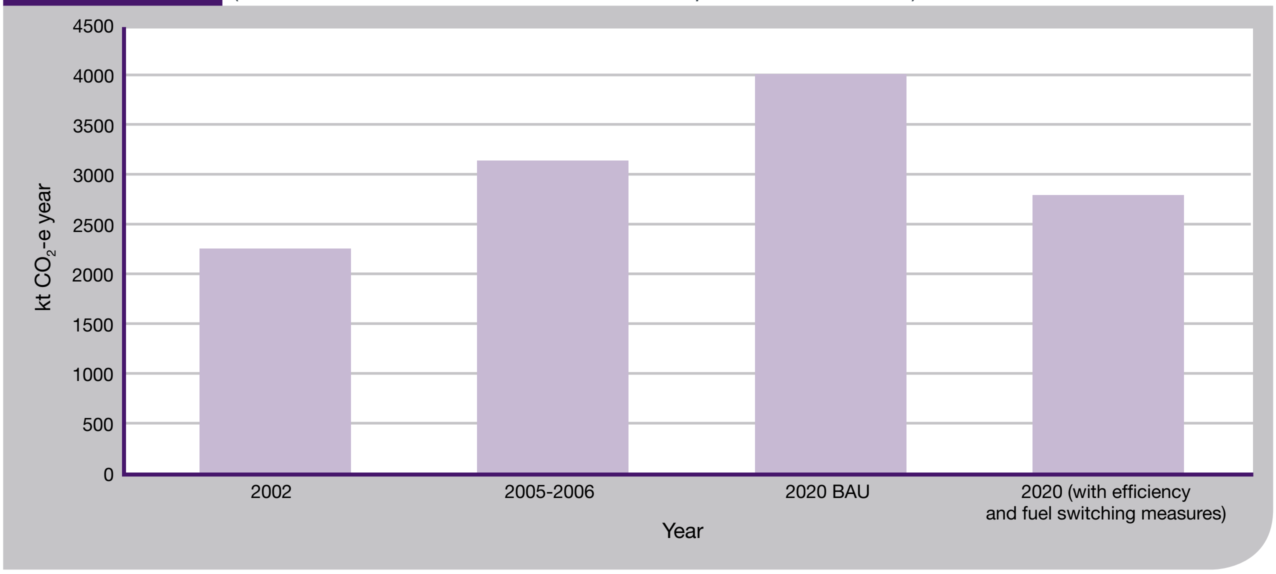
b) implementation of new and renewable energy use **greening the power supply**, and

c) Sequestration of the residual emissions to deliver zero net emissions or **offsetting**.

This research focuses on part a) the emissions reductions delivered by the built environment which has partly become embodied within the 1200 Buildings Program.

The reported emissions in 2002 were 3.75 million tonnes of carbon dioxide equivalent (t CO_2-e) and commercial buildings were said to account for 59% of that total (2.21 million t CO_2-e). Commercial sector emissions are estimated to be 9.9 t CO_2-e per employee by 2020 and a reduction to 4.1 t CO_2-e is the target. This figure translates into an emission reduction target of 1004 kt CO_2-e on 2020 business as usual emissions (see figure 1) and represents a decrease of 8% on 2005-6 levels and 25% on 2020 predicted emissions. For existing office buildings a large scale program to retrofit around 70% of total stock or 1200 buildings has been established.

Figure 1 **Commercial sector greenhouse gas emissions from 2002, 2005-6 to 2020** (under a business as usual and a *Zero Net Update 2008* scenario)

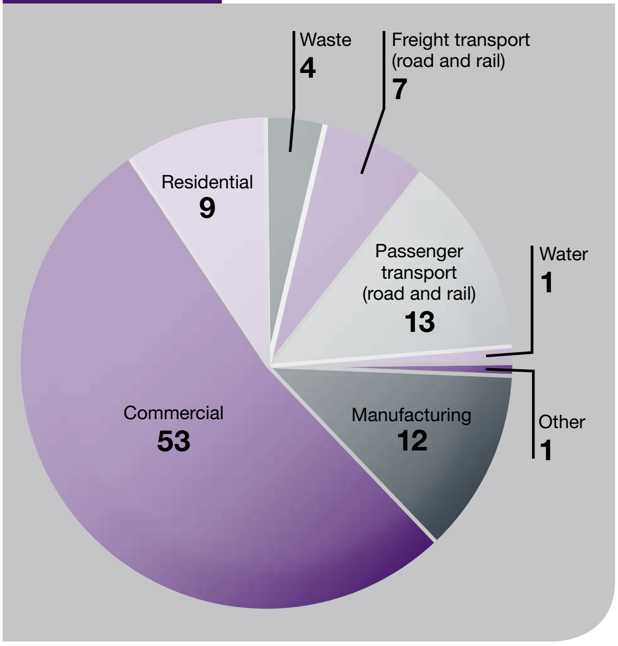


Source: City of Melbourne 2008

2.2 The 1200 Buildings Program

Figure 2 shows the emissions as a percentage within each sector in the Melbourne CBD, clearly commercial buildings are responsible for over half (53%) of all city emissions and represent a key area where emissions reductions can be delivered.

Figure 2 **Greenhouse gas emissions by sector for the City of Melbourne 2005-6**



Source: City of Melbourne 2008

The City of Melbourne collated data relating to commercial stationary energy from 2002, 2005-6, and set out the 2020 target (shown in table 2) shown both as a total figure and an amount per employee. The reductions are also expressed as a percentage and highlight what an ambitious target it is.

Table 3 Total commercial sector emissions under a business as usual and a Zero Net Update 2008 scenario

GHG Emissions		
	Commercial stationary energy	
	Total	Per commercial employee
Baseline / target	Kt CO_2-e/year	t CO_2.e/year
2002	2,212.5	9.8
2002 Victorian average		
2005-6 baseline	3,235	9.9
2020 target	1,659	4.1
% change on 2005-6	-47.7%	-58.2%

Source: City of Melbourne 2008

Table 4 Combined emissions reduction strategies in the commercial sector

Commercial reduction strategies	Scale of reductions ($ktCO_2$-e)		
	Lower	Medium	High
Existing office buildings	193	285	383
New office buildings	0	134	163
Education, health & community	29	43	57
Retail and wholesale (existing)	26	52	78
Retail and wholesale (new)			137
Hotels (existing)			83
Hotels (new)			103
TOTAL	248	514	1004

Source: City of Melbourne 2008

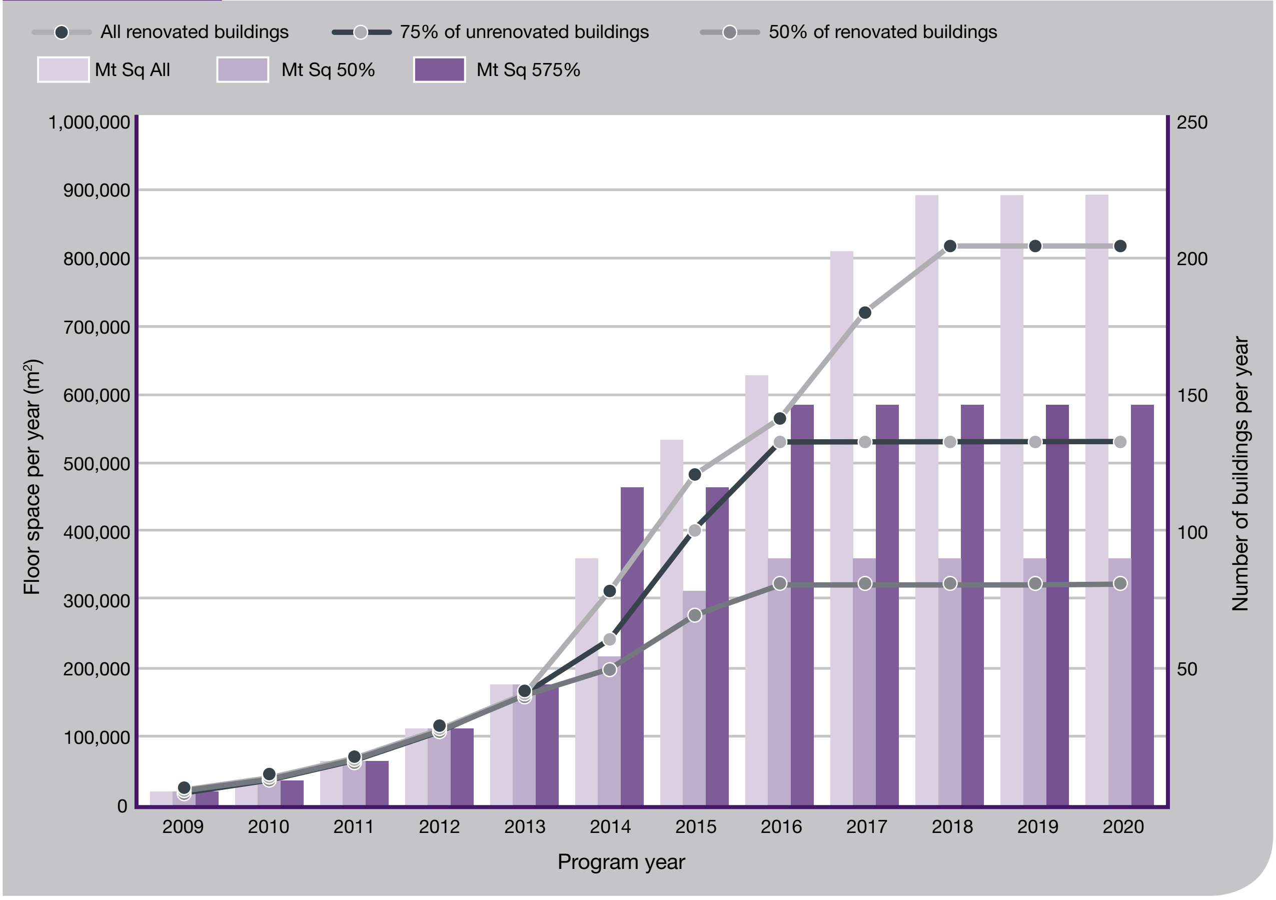
The city has further broken down the figures and identified reduction targets within low, medium and high scenarios across the commercial sector (as shown in table 4). With 7.7 million square metres of office space and around 1800 commercial office buildings in the City of Melbourne, a target of retrofit to 5.2 million square metres within 1200 buildings has been set. It is estimated that an average performance improvement of around 38% is required in the high target, whilst 50% and 75% retrofitting of buildings are required in the lower and medium targets (City of Melbourne, 2008). The current targets are based on the Australian Building Greenhouse Rating (ABGR) standard of 4.5 stars out of a possible 6, however in 2012 the City of Melbourne stated that it intends to raise the target to 5 stars ABGR. The National Australian Built Environment Rating System (NABERS) rating is either a base building energy rating or whole building energy rating.

- A base building rating covers the performance of the building's central services and common areas, which are usually managed by the building owner.
- A whole building rating also covers the tenanted space. These ratings are only disclosed when there is inadequate metering to obtain a base building rating

NABERS Energy rates the energy efficiency of commercial buildings by comparing them against a set of benchmarks developed using actual building performance data. NABERS rates performance on a scale of 0 to 6 stars. A 6 star rating is awarded for market leading performance, and represents a 50% reduction in greenhouse gas emissions or water use from a 5 star rating. A 0-star rating means the building is performing well below average and has considerable scope for improvement.

The City of Melbourne has outlined how they predict the program will roll out. Starting from a low take up in the early years 2009 to 2012, there is relatively little activity across all parts of the commercial building sector. In 2011 for example it was predicted that approximately 20 or so buildings would take up the program. However from 2013 onwards, it is suggested that activity increases across all sections until 2017 when around 220 buildings per year would be within the program. This projection was made in 2008 when the depth and breadth of the ongoing impact of the Global Financial Crisis was unknown and an analysis of current progress should consider this impact.

Figure 3 Options for a program to retrofit City of Melbourne unrenovated buildings



Source: City of Melbourne 2008

2.3 Mandatory Disclosure of Energy Performance

Under the *Building Energy Efficiency Disclosure Act 2010*, there are mandatory obligations applicable to many commercial buildings. The Act, implemented through the Commercial Building Disclosure program, forms part of a package of measures to encourage building energy efficiency developed by the Australian, state and territory governments. The Commercial Building Disclosure is a national program to improve the energy efficiency of Australia's largest office buildings and is managed by the Australian Government Department of Climate Change and Energy Efficiency.

Most sellers or lessors of office space of 2,000 square metres or more are required to obtain and disclose a current Building Energy Efficiency Certificate (BEEC). A BEEC is comprised of:

- a NABERS Energy star rating for the building
- an assessment of tenancy lighting in the area of the building that is being sold or leased and
- general energy efficiency guidance

BEECs are valid for 12 months and must be publicly accessible on the online Building Energy Efficiency Register. Certain exceptions and exemptions apply. From 1 November 2011 a full Building Energy Efficiency Certificate (BEEC) needs to be disclosed[2].

2 http://cbd.gov.au/default.aspx?test=true

2.4 Existing office buildings and sustainability attributes

This section outlines office building typologies and sustainability issues. Buildings are evaluated in terms of likely energy consumption patterns on the basis of size, configuration, methods of ventilation and the presence of air-conditioning.

Table 5 Office typologies and energy profiles

Office typology	Size	Configuration	Ventilation	Energy consumption
1 – Naturally ventilated	100-3000m^2	Cellular	Natural	Lowest
2 – Naturally ventilated	500-4000m^2	Open plan	Natural	
3 – air conditioned (standard)	2000-8000m^2		Air conditioned	
4 – air conditioned (prestige)	4000-20000m^2		Air conditioned	Highest (3x lowest)

Heating, hot water and cooling are the largest consumers of energy across all typologies and are at the centre of efforts to reduce emissions. Energy use varies for tenants and managers and this creates some issues in respect of motivations for sustainable retrofit. The respective responsibilities are outlined in Table 6 below.

Clearly the managers have an opportunity to make significant energy savings. The savings which may be achieved can be as high as 70% but are typically 30 to 50% (City of Melbourne, 2008). A retrofit which takes building performance from average (i.e. 3 stars NABERS) to best practice (5 star NABERS) represents a 38% improvement in performance (City of Melbourne, 2008). The typical measures are;

Table 6 Responsibilities for energy in office buildings

Energy use for buildings managers	Energy use in buildings for tenants
Heating and hot water (gas or heating oil)	office equipment
Cooling (chillers, air-conditioning plant, condensers and cooling towers)	catering
Fans, pumps and controls	other electricity (print rooms)
Humidification	computer communication rooms
Lighting	

Table 7 Typical retrofit measures for office buildings

Measure	Notes
Air conditioning	Attend to running times, volumetric capacity and operating pressure.
Office appliances	Use more efficient equipment and reduce standby losses.
Insulation	Improve thermal performance
Heating and ventilation	Use building energy management system (BMS), use heat recovery and perimeter heating for preheating
Lighting	Use energy efficient fittings, timers, linear fluorescent lights for interior, exterior and parking lighting
Water heating	Use efficient systems and technologies such as solar

2.5 Property attributes associated with office building retrofit

Many studies have sought to identify the specific property attribute(s) which make a retrofit 'successful', though the concept of 'successful' varies from stakeholder to stakeholder (section 2.6). The categories of attributes typically identified in the literature relating to 'successful' building retrofit are economic, physical, location and land use, legal, social and environmental and are shown in table 8.

Table 8 Building retrofit attributes grouped into categories

Category	Attribute
Economic factors	Current value Investment value Yields Increase in value post retrofit Construction and development costs Convertibility (ease of conversion to other use and costs associated with the conversion)
Physical factors	Building height/number of storeys Floor plate size Shape of floor plate Service core location Elasticity (ability to extend laterally or vertically) Degree of attachment to other buildings Access to building Height of floors Structure Floor strength Distance between columns Frame Deconstruction (safe efficient and speedily) Expandability (volume and capacity) Flexibility (space planning) Technological and convertibility Dis-aggregability (reusability / recyclability)
Location and land use factors	Transport Access (proximity to airports, motorways, train stations, public transport nodes, buses and trams) Land uses (commercial, residential, retail and industrial or mixed use such as office and retail) Existing planning zones Rezoning potential Density of occupation
Legal factors	Ownership – tenure Occupation – multiple or single tenants Building codes Fire codes Access acts Health and safety issues Convertibility
Social factors	Community benefits – historic listing Transport noise Retention of cultural past Urban regeneration Aesthetics Provision of additional facilities / amenities Proximity to hostile factors Stigma
Environmental factors	Internal air quality Internal environment quality Existence of hazardous materials (asbestos) Sustainability issues

2.5.1 Economic attributes

Retrofit has to be economically viable to be successful, although sometimes economic costs can be traded against social and environmental gains (Swallow, 1997; Ball, 2002; Highfield, 2000; Kincaid, 2002; Snyder, 2005; Kersting, 2006). This perspective comes from triple bottom line accounting theory that has developed with the increased importance of sustainability. In 2007 the United Nations (UN) ratified the standards for urban and community accounting. In triple bottom line accounting environmental issues are taken into account along with social and economic factors.

A critical aspect is to ascertain the clients intentions regarding the end product, for example, do they wish to sell the adapted building on the open market or; *do they intend to occupy the building themselves?* (Swallow, 1997). Based on the two different outcomes, different features may be more or less important within the retrofit and may lead to different investment values and yields. A study on adaptability in Norwegian office buildings found that owner occupied office stock had a higher incidence of 'adaptability' criteria compared to speculatively designed office buildings. Criteria which had been identified as being associated with ease of retrofit were found more often in owner occupied buildings and the researcher concluded owner occupied buildings would be more adaptable for long term occupation and thereby provide a greater return on investment over the whole building lifecycle (Arge, 2005).

Clearly there has to be market demand to bring about economically viable retrofit. Positive user demand and active marketing by stakeholders were important criteria in successful building retrofit in the reuse of vacant stock in Stoke-on-Trent, England (Ball, 2002). In that market, user demand was for vacant industrial premises adapted specifically to provide low cost accommodation for new start-up businesses (Ibid.). Thus market research into demand is an important aspect of economically 'successful' building retrofit because it affects the economic attributes such as yields, post retrofit value and investment.

Another economic indicator is pre and post retrofit value, where for a retrofit to be considered viable or successful the result should be a net increase in value post retrofit. By measuring the market value of refurbished residential blocks in Hong Kong one study found a positive relationship between retrofit and value (Chau et al., 2003). Equally where property is adapted for rent, an increase in rental levels should be achieved for the post adapted property. Another positive economic indicator is to have lower vacancy rates in adapted buildings compared to non-adapted stock; which was the case for adapted stock in the Stoke-on-Trent study (Ball, 2002).

The costs of retrofit are often cheaper than new build, because for example, it is possible to reuse foundations and superstructure and offset the costs of these elements of the building. Total costs are an important economic characteristic of retrofit (Ball, 2002; Highfield, 2000; Douglas, 2006; Davis Langdon, 2008). Typically owners are able to deliver a product to the market at around 66% of the costs compared to a new build development. However where buildings are complex, heritage listed, and or have problems with deleterious materials then retrofit costs can surpass a new build project (Bullen, 2007).

Depending on the condition of the original building it is possible to increase the overall quality with retrofit (Boyd and Jankovic, 1993; Isaacs (in Baird et al.), 1996; Swallow, 1997; Snyder, 2005; Kersting, 2006). Quality is measured in various ways but generally and across all land uses, it can either provide a greater number of amenity features, attributes and/or a higher standard of services, features, fixtures and fittings. In Australia, for example, offices are graded by the Property Council of Australia as Premium (the best quality and highest rental levels), A, B, C and D grade. Grade D is the lowest office grade with the least level of services and amenity and the lowest rental levels. Thus it is possible with a well-planned retrofit to increase the office quality grade from one band to another and simultaneously increase the rental and capital value of the building. However, the capacity to upgrade an office building from one grade to a higher grade is dependent on the condition and location of the building (Ibid.).

A UK study showed that post retrofit buildings typically had lower running and operating costs than prior to the retrofit (Kincaid, 2002). The lower running costs accrue as a benefit of technological advances in building services since the original installation was made. This reduction in running costs is another economic characteristic that could contribute to higher rental levels or higher capital values as noted in table 2.2 and is another positive economic characteristic of retrofit (Ibid.).

Given that it is important to know whether the property will be sold or leased post retrofit, arguably knowing the tenure of the property is important (Swallow, 1997), that is to say; is the person undertaking the retrofit an owner occupier or lessee? Owner occupiers are more likely to undertake larger scale retrofit than lessees who would be more likely to undertake minor fit outs tailored specifically to their needs. Furthermore: who is the owner? Are they private individuals or is the owner an institutional owner, i.e. is the property part of a portfolio of properties managed professionally by a financial institution? Different types of owner are likely to undertake different types and levels of retrofit. Institutional investors would buy and sell property in the short, medium and long term for profit and would be more likely to use professional property consultants to advise them on the market conditions and retrofit potential. Whereas private individuals may or may not have such ready and immediate access to such professional advice, thus the tenure or ownership of the building may contribute to the degree and extent of retrofit activity.

2.5.2 Physical attributes

Not surprisingly, the most prevalent category of building related attributes found in the literature is physical characteristics (table 8). Clearly the physical building itself determines to a large extent whether retrofit is possible and or desirable. All studies identified the age of the building as an important physical consideration (Barras and Clark, 1996; Ball, 2002; Fianchini, 2007; Nutt et al., 1976), with services and plant wearing out after 15 to 20 years and the building envelope and fabric requiring replacement after 25 years or so dependent on materials used in construction and the degree of exposure and prevailing climatic conditions.

Some buildings, such as those constructed in the 1960s feature certain forms of construction and materials (e.g. asbestos) which makes retrofit more expensive or challenging because of the need to comply with strict legal requirements for safe removal (Bullen, 2007). The use of asbestos in construction, usually as a form of fire protection, creates a problem for retrofit associated with the physical attributes of the property because of the challenges of removal without destroying or compromising the structural integrity of parts of the building.

Building height was an important factor in retrofit (Povall and Eley in Markus, 1979, Gann and Barlow, 1996). The type of construction of the frame and the condition of the frame is important. Many studies concluded steel framed buildings were more easily adapted to new configurations of internal space because of the ease of cutting into steel beams compared to concrete structures (Ibid.). A study about integrating the past and present through retrofit noted the frame and construction type as significant factors (Kersting, 2006). A frame in sound structural condition has the potential to accommodate retrofit, whereas a building frame in poor condition will require extensive costly works to accommodate a new or changed use which impacts on economic viability.

Floor size in the London office market was found to be an important characteristic in building retrofit (Kincaid, 2002). Office buildings with unusually shaped floor plates, or sizes were more difficult to adapt than those having large open plan space that was suited to sub-division in a number of ways for different user needs (Ibid.). The Swiss Re Tower in London, with its circular floor plate failed to lease as quickly as other buildings with a similar specification because users found the curved floor plate created unusable space. Buildings with unusual irregular plan shapes are harder to adapt to suit a wider range of new users (Kincaid, 2002; Povall and Eley in Markus, 1979). In conclusion whether a building has a deep plan, narrow plan with a wide frontage, a narrow plan, an irregular or a curved plan shape was found to impact on a building's adaptability and market appeal.

Other studies noted the location of the services core was an important consideration (Gann and Barlow, 1996; Snyder, 2005; Szarejko and Trocka-Leszczynska, 2007). Services cores in commercial buildings can be located centrally, offset towards the front or rear of the building or in dual/multiple locations. The location of the services core affects the ability to sub-divide the space, for example it affects how services can be delivered to various parts of areas of the building. Therefore depending on the size and shape of the floor plates and whether the demand is for large or smaller floor areas, the location of the services core can affect how easy and costly retrofit might be. Often a central location will give greater scope for sub-division of the floor plate whilst minimising corridor and circulation space.

The site on which the building is located is perceived to affect the retrofit potential of property. For example whether a building was detached or attached on one or more sides affects the ease or desirability for retrofit. With less attachment to other buildings contractors are able to undertake their operations with greater speed and less disruption to any remaining building occupants (Povall and Eley in Markus,1979; Isaacs in Baird et al., 1996). Similarly, many researchers noted building access or, the number of entry and exit points, is a vital characteristic affecting retrofit potential across a range of property types (Povall and Eley in Markus, 1979; Gann and Barlow, 1996; Ball, 2002; Snyder, 2005; Kerstin, 2006; Remøy and van der Voordt, 2006). The more access points a building has, the more flexibility there is for retrofit.

A European office retrofit study found that an optimum floor to floor height of a minimum 3.60 metres gross or 2.70 metres net existed for office retrofits (Arge, 2005). In Australia there will be a preference for certain floor to floor heights for some types of building retrofit. Whilst no published information in relation to adapting existing buildings was found, design guides for new buildings state the optimum floor to ceiling heights in offices are 3.6 metres for ground floors and 2.6 metres for upper floors (Ryde, 2006). Note that Ryde (2006) measured floor to ceiling heights and Australian conventions, whereas the Arge (2005) study measured floor to floor height, which includes the floor slab and European practices.

Building width is an important criterion in retrofit; one study established a benchmark for building width in retrofits of 15 to 17 metres (Povall and Eley in Markus, 1979) which was substantiated 26 years later (Arge, 2005). The studies showed that buildings of certain widths were more adaptable than others; that is they were able to accommodate a range of space configurations and user needs more frequently. Similarly the technical grid, or the distance between the structural columns on the floor plate, within the building affected the ease with which it could be adapted for new and other uses and an optimum or desirable grid of 2.40 metres between columns was identified (Ibid.).

A study into London office buildings concluded that floor strength was an important factor in retrofit (Kincaid, 2002). Buildings with floor strength of 3 kN/m^2 or less suited residential uses, those between 3 to 5 kN/m^2 suited retail, office and hospital uses, those between 5 to 10 kN/m^2 suited light industrial uses and those buildings with floor strength above 10 kN/m^2 fitted industrial and warehouse uses. Thus, in retrofit, floor strength has to be assessed to determine the land uses which are possible and suited physically to the existing floor structure. For example, it is not possible to accommodate office use in a building with existing floor strength of 3kN/m^2, unless strengthening works or replacement of the floor is undertaken.

In an examination of office buildings and services components to assess retrofit potential, it was found that within the technical grid the type of heating ventilation and air conditioning equipment was significant and whether an allowance had been made to accommodate extra capacity in the original design and specification (Arge, 2005). Furthermore the provision of raised floors in office buildings allowed for changes and upgrading of cabling for information technology (IT) systems to be undertaken with ease. It was found that zone based internet communication technology provision allowed for more flexibility and adaptability within office building and was a sought after characteristic (Ibid.). Another feature within the technical grid of office buildings is the suspended ceiling grid where horizontal and vertical sound proof barriers could be fitted to zone off parts of the floor plate for different users. Each of these features of existing buildings was grouped in the category labelled 'generality' (Ibid.).

'Flexibility' is focussed on the attributes buildings possess which make them easier to change and adapt (Ibid.). Within flexibility, modularity means that the building is made up of modules or smaller units which can be rearranged, replaced, combined, or interchanged easily was important. Another vital aspect identified was termed 'plug and play' building elements, which allow for a fast change of layout, or change of services and wall systems. For example, office partitions that can be easily dismantled and re-erected to accommodate changes in space plans (Ibid.). It was argued that flat soundproof ceilings were required to allow for an easy change of wall partitions to ensure there were no problems associated with sound transmission following retrofit (Ibid.).

A study into retrofit attributes for office buildings found potential for vertical and lateral extension was an important characteristic (Ibid.). Buildings which offered scope for either lateral or vertical extension were considered more adaptable than others because the overall size of the building could be increased to suit new uses and occupiers. The same study concluded 'elasticity' was an essential characteristic for office retrofits. Elasticity refers to the ease of extending the building either laterally or vertically. There were other attributes within elasticity such as building form and organisational space and ease of compartmentalisation. Compartmentalisation is a term which covers the sub-division of space for different users. Functional organisation of space was found to be important, and deemed to be the ease with which a change of function can be accommodated within the building. In offices, the provision of fire sprinklers allows for large continuous spaces to be provided where desired and for the building regulations to be complied with. The final component of elasticity within office buildings is the potential for sub-division for either letting or sale purposes. Buildings which can be easily sub-divided for sale or lease to a number of different tenants or owners were seen as highly desirable, allowing owner's to keep abreast of changes in market demand for office space (Ibid.).

2.5.3 Locational and land use attributes

Previous studies considered the location of the building and how it affects retrofit (Kincaid, 2002; Douglas, 2006; Highfield, 2000) as important. Location is considered in the context of the proximity to public transport which has been noted as an environmentally positive aspect in building retrofit because it reduces private car use and the associated greenhouse gas emissions. The amount of on-site parking provision is considered important for some retrofits where little or no public transport is available (Douglas, 2006).

Previous research has shown that land use attributes are important in determining whether building retrofit is successful or otherwise (Arge, 2005). The existing land use affects the potential for a new or changed land use to some degree, for example an office to a residential change of use. The existing planning zone determines legally what is considered permissible development in a designated area. In Melbourne the term adopted by the legislation, the Planning and Environment Regulations 1998, is planning zone. The planning zones are coded for particular land uses such as, residential (R1Z), business (B1Z), mixed use zone (MUZ) or other. The zones are listed in the planning scheme and each zone has a purpose and set of requirements. It is possible to have sites rezoned in the legislation. For example industrial or office zones can be reclassed for residential land uses. A proactive policy from the city authority in Toronto during the 1990s promoted increased rates of retrofit from office use to residential; thus rezoning potential of the land is an important criterion to note in assessing retrofit (Heath, 2001). Operational land use issues include the density of occupation of the land. Within Australia, as in other countries, there is an ongoing planning land use debate about increasing density of the built environment to prevent erosion of green belt land within and around the existing city (City of Melbourne, 2005). Increasingly city authorities in Melbourne have been amenable to increasing density of occupation as part of a strategy for increasing sustainability of the city centre.

2.5.4 Legal attributes

Buildings have legal issues attached to ownership, transfer of ownership and in regard to leasing (table 2.2). Previous studies concluded that retrofit is affected by the tenure of the property, for example, is the person undertaking the retrofit the owner or a lessee? (Swallow, 1997). The period of time for which the party has an interest in the building is important and may affect the amount of funds they are willing to invest in retrofit. For example, an owner has an interest in perpetuity whereas a lessee's interest will last for the duration of the lease term, typically five years in Melbourne.

Owners can be institutional owners or private owners. Institutional owners are defined as pension or superannuation funds, financial companies or organisations which invest in property for stakeholders such as investors. As such institutional owners seek to maximise the return on investment in property or buildings for their stakeholders or shareholders, and will utilise professional building and property consultants to ensure this is achieved. Institutional investors are likely to use professional consultants to advise when retrofit has become economically and physically desirable.

Private owners may be companies or individuals who may or may not use professional property and construction consultants to the same degree that institutional owners do. Private owners may reside offshore and may hold the property for a number of reasons, for example for future development or for rental income or capital growth. Private owners may engage in less or more retrofit; however this is unknown at present as no retrofit studies recorded such data.

Another legal aspect which affects the ability to undertake retrofit is the way the building is occupied, for example some buildings have single tenants and when the lease expires there is an opportunity to adapt. However, when a building has multiple tenants, it is unlikely that all leases will expire simultaneously, therefore the building may be partly empty (and not earning income) for a period before all leases have expired and the building is available for retrofit. Alternatively an owner can negotiate with tenants to terminate leases early and compensate the tenant or to decant tenants, temporarily or permanently, to other floors within the building whilst retrofit is undertaken. Such an approach of temporarily decanting tenants was adopted by the Kador Group in their retrofit of the 28 storey building at 500 Collins Street in Melbourne where three floors at a time were adapted and the existing tenants were moved around to suit the building program (Your Building, 2009).

The final legal consideration noted in the literature on retrofit is the building classification (Arge, 2005). Under the Building Code of Australia (BCA) 1994, each building type has a classification which is given a number. For example, residential buildings are either Class 1 or 10 or, for high rise or multi unit residential buildings Class 2. Office buildings are Class 5 and shops or retail buildings are Class 6 in the BCA. Different building standards or regulations apply to the different classes of buildings within the BCA and where an retrofit involves a change of use from one class to another, different standards will have to be met within certain sections of the BCA. Thus within Australia, the building Class may favour change of use retrofits from one Class to others to a greater or lesser extent. For example changing from residential to office use may be more expensive and complex than a change from office to residential classification under the BCA. In 1996 the BCA changed fundamentally from a 'deemed to satisfy' code to a performance based code. A performance based building code allows architects, designers and engineers to demonstrate that code standards are met through a more flexible way than previously. It is anticipated that this change to the BCA would favour increased retrofit.

2.5.5 Social attributes

This section examines attributes associated with social attributes and property retrofits as shown in table 2.2. For example historic listing is a means of protecting architecturally or socially significant buildings for the wider benefit of society. The benefits of adapting heritage listed buildings are that the cultural and social values embodied within the building are retained for the wider benefit of the community (Ball, 2002). A US study concurred with this view of social and cultural worth when researching retrofit of culturally significant industrial buildings (Snyder, 2005). Though it is noted retrofits involving listed buildings can be more expensive than unlisted building retrofits because of the additional costs involved in using traditional building materials, techniques and craftspeople (Bullen, 2007). Historic listing can be, and is, categorised under legal issues as well as social.

Numerous studies noted the benefit of proactive policies and or legislation in building retrofit (Chudley, 1981; Gann and Barlow, 1996; Highfield, 2000; Heath, 2001; Ball, 2002; Snyder, 2005; Burby et al., 2006; Kersting, 2006; Galvan, 2006; Shipley et al., 2006). A 2001 study into the retrofit of commercial office buildings into residential buildings in Toronto and London, found that the rate of retrofit was higher in Toronto because of a proactive planning policy (Heath, 2001). Studies into urban regeneration in the London and Bristol dockland areas found that proactive policy and legislation enhanced the retention of existing building stock within those areas (Bromley et al., 2005).

A proactive policy for building rehabilitation was adopted in the New Jersey building codes and resulted in an increase in the amount and scope of retrofit in that jurisdiction and was cited as evidence of the way legislation can influence retrofit outcomes for the social benefit of the community (Burby et al., 2006). The study examined whether code compliance adversely affected rehabilitation of existing buildings and found that the rehabilitation sub code introduced by the New Jersey authority was statistically significant in its impact on the number of residential rehabilitation projects and that there was a positive effect on the attitudes towards legislation (Ibid.). The building codes pre 1994 and post 2002 were compared to evaluate whether a difference existed and examined 117 jurisdictions using a multivariate analysis (Ibid.).

Another social aspect of building retrofit is that 'hostile factors' can adversely affect the proposed project (table 2.2). Hostile factors include noise pollution, proximity to a noisy motorway or air traffic noise; such environments tend to be less desirable for people hence the term 'hostile'. A further category of a hostile factor is the presence of deleterious materials with in a building such as asbestos. The presence of these materials presents a recognised health hazard to building users and occupiers and remediation and removal costs are high. Further examples are the presence of volatile organic compounds in building materials such as formaldehydes in glues which emit gas and can cause allergic reactions in building occupants and users. The presence of lead in pipe-work can erode in soft water and be ingested by building occupants causing cancers. Another building related illness is caused when legionella bacteria migrate from wet cooling towers associated with building air conditioning and infect occupants with 'legionnaire's disease'. In summary, the presence of hostile factors can present social and economic barriers which can drive up costs to a point where retrofit becomes uneconomical (Bullen, 2007).

A study into re-use of derelict buildings found some building types have a social stigma which makes retrofit problematic, for example mental asylums were difficult building types to successfully adapt because of the negative emotions associated with the previous use (Binder, 2003). It might be expected that the re-use of prison buildings would have similar issues with social stigma; however in Melbourne the former Pentridge Prison in Coburg has been successfully adapted into residential use (Wilkinson et al., 2009). It appears that social stigma is an example of a social aspect which varies from one location to another according to local cultural norms.

2.5.6 Environmental attributes

With the increasing interest in sustainability in the built environment, there has been an increase in the scope and extent of environmental aspects of retrofit (Boyd and Jankovic, 1993; Kincaid, 2002; Bullen, 2007). There is sometimes an overlap with social, economic and location aspects, for example proximity to public transport provides environmental, location, economic and social benefits. This overlap means that some of the attributes can be interpreted on multiple levels.

The most significant environmental impact of buildings is the greenhouse gas emissions associated with energy use (Douglas, 2006; UN, 2007). Buildings which have been assessed under recognised environmental assessment methods such as the UK's BREEAM, or LEED in the USA, or GreenStar in Australia have met specified standards in respect of a range of sustainability / environmental criteria including energy use. A UK study stated energy consumption should be noted on a Watts per metre squared basis to establish whether the building was a low, medium or high emitter of greenhouse gas emissions, similar conclusions were reached by others (Davis Langdon, 2008; Arup, 2008; Kincaid, 2002).

In the Australian commercial property market the key environmental assessment method acknowledged by the market is GreenStar which is developed and monitored by the Green Building Council of Australia. The Australian Building Greenhouse Rating (ABGR) which measures energy consumption and emissions has now been incorporated into the National Australian Built Environment Rating System (NABERS) (Australian Green Building Council, 2010. Department of Environment Climate Change and Water, 2010). NABERS is a national initiative managed by the NSW Department of Environment, Climate Change and Water (NABERS, 2011). NABERS is a voluntary performance-based rating system for existing buildings, including offices, which rates buildings on the basis of measured operational impacts on the environment. NABERS ratings for offices include NABERS Energy (previously ABGR), NABERS Water, NABERS Waste and NABERS Indoor Environment on a scale to 5 stars. Each of these tools has been designed to use the same methodology as the ABGR scheme. Buildings which have been accredited under these schemes have demonstrated a level of sustainability. Green Star covers a range of building types such as retail, education, office (design), office (as built), office (interiors) with office (existing building), mixed use, healthcare and industrial buildings under pilot scheme development. Buildings which have a Green Star rating contain environmental attributes acknowledged by the market in terms of energy and water consumption, materials specification, waste and recycling and management (Australian Green Building Council, 2010).

One Australian study advocated the need to adapt existing offices to meet the Bali Road Map Agreement of December 2007, which asked for deep cuts of 40% in greenhouse gas (GHG) emissions by 2020 to mitigate climate change (Davis Langdon, 2008). The report noted that existing Melbourne office buildings need to be adapted to an ABGR rating of 4.5 to meet 40% reductions in GHG emissions. The report concluded that emissions trading would not deliver sufficient reductions and that capital injection or incentives are required to induce building owners to undertake retrofit (Ibid.). In Australia it was estimated that four billion Australian dollars over 12 years is required in incentives to get the reductions needed in commercial buildings (Ibid.). The benefits for owners of existing buildings are lower energy costs, reduced impact of future emissions trading schemes, reduced emissions, reduced obsolescence, good risk management strategy, more competitive buildings, improved capital value and increased rental growth.

Furthermore the research concluded that investment in energy efficiency of existing buildings has the potential to reduce greenhouse gas emissions by 30-35% within 20 years; faster than alternative approaches (Ibid.). Australia is committed by the federal government to reduce emissions between 25-40% by 2020 (Lorenz et al., 2008). There are approximately 130 million square metres of existing buildings in Australia, of which offices comprise 20.5 million square metres of that space and emit 6.6 million tonnes of greenhouse gas per annum (Department of Environment, Climate Change and Water, 2010a). There is potential to have a significant effect on emissions reductions through retrofit (Boyd and Jankovic, 1993; Kincaid, 2002; Davis Langdon, 2008; Ball, 2002; Bullen, 2007; Department of Environment and Heritage, 2005).

Given that 85% of all Australian offices are over 10 years old, with the average age of Australian offices being 27 yrs and in Melbourne 31 years, retrofit of existing buildings is imperative; it would take 290 years to regain the embodied energy in new building through its more efficient performance (Davis Langdon, 2008). A review of research into a range of existing offices in Melbourne covering a range of office quality grades, from good quality to low quality, using the Australian Building Greenhouse (ABGR) tool reveals a rating of 2 stars or less which represents very poor performance (Ibid.). The conclusions were that there is an urgent need to act quickly if greenhouse gas emissions cuts are to be achieved within the City of Melbourne timeframe of carbon neutrality by 2020. Therefore energy performance and the potential for improvement are key environmental retrofit criteria (Ibid.).

With the recent drought in Australia from 2000 to the end of 2010, water consumption is a very important sustainability indicator (GBCA, 2010). Water economy is a feature of environmental assessment tools such as the GreenStar rating tool (Ibid.). Most building stock was constructed pre drought and paid little attention to minimising water consumption. Retrofit offers an opportunity to reduce water and energy consumption through the retrofit of measures that reduce consumption at the point of use, recycle water, harvest rainwater and re-use water. Such measures increase sustainability and reduce the overall environmental impact of the built environment.

A further environmental impact relating to buildings is the means of transport that occupiers use to travel to the building (Kincaid, 2002; Davis Langdon, 2008). The use of public transport has less environmental impact and emissions than occupiers driving their cars to work, and thus proximity to public transport is perceived as a positive environmental feature of a building and is included in environmental assessments of buildings (Davis Langdon, 2008). Conversely having car parking provision on site is perceived as a negative within environmental rating tools for office buildings (GBCA, 2010). However car-parking is regarded as desirable in the Property Council of Australia building quality grading matrix and represents a contradiction in terms of market perceptions of quality and the perception of environmental features as being highly desirable.

These are valid environmental building retrofit criteria and need to be assessed on an individual building basis. Other relevant environmental aspects identified as important in building retrofit are acid rain pollution which causes erosion of stone on buildings (Douglas, 2006; Boyd and Jankovic, 1993; Ball, 2002; Bullen, 2007). Ozone depletion leads to greater solar degradation of building materials and a faster decline on physical condition (Douglas, 2006). The presence of toxins in building materials can cause allergic reactions in people such as eye irritation. A significant environmental impact of the built environment is resource consumption and depletion as 40% of the world's resources are consumed by the built environment. Furthermore during the construction phase negative environmental impacts are excessive noise, dust and dirt (Douglas, 2006; Boyd and Jankovic, 1993; Ball, 2002; Bullen, 2007). This research includes some key environmental criteria involved in retrofit events and decisions. However given that sustainability was mandated in Part J of the Building Code of Australia as energy efficiency in 2006 and the research covers the period to 2008, the influence of environmental attributes may not feature strongly. The factors affecting building retrofit decisions are illustrated conceptually in figure 2.4, however this figure omits the significance of the various influencing factors on retrofit decisions and this is one of the knowledge gaps in this field.

2.5.7 Other factors

It is generally accepted that there are other exogenous factors that affect decision-making in building retrofit that are difficult to isolate and explicitly account for, although it is unreasonable to ignore their effect. These factors are therefore represented as 'other factors' in the conceptual model presented in figure 3.2. Typical examples in this category are;

a) Dramatic changes in the global economy (i.e. the global financial crisis in 2008 /2009) affect the financial markets highlighting insecurity and the relative safety and stability of property.

b) Unforeseen acts of terrorism that affects the global economy, highlighting the insecurity of the share market and the safe haven property offers, for example, the collapse of the World Trade Towers on the 9th September 2001.

c) Modification to the tax system that affect the costs of building retrofit.

d) Modification to the planning legislation and building codes that may incentivise the new building or the retrofit market.

Whilst acknowledging that these other factors may have some influence on the rate and type of building retrofit events, a separate analysis was not included in this research. In summary the nature of building retrofit and its complex relationship with influencing factors ensured that it is practically impossible to account for and consider *every* influence on *every* building retrofit event. Whilst the inclusion of 'other factors' in this manner did not ignore their potential influence upon retrofit events, they fall outside the scope of this research. This research adopts a different perspective by examining all retrofit events that have occurred, and without conducting interviews or surveys there is no stakeholder view to bias or influence the findings. Although the numerous stakeholders and their perspectives do influence individual retrofit cases, it is not within the remit of this research to investigate and quantify their impacts or effects.

2.6 Stakeholder in building retrofit

Decision-making in retrofit is made more complex because of the multitude of stakeholders who influence the decision to varying degrees and at different points in the process (Ball, 2002; Kincaid, 2002). As Ohemeng (1996) found the numerous stakeholders represent interests which are so diverse that he was able to focus on one group only, building owners, in his decision-making model. Each stakeholder represents a different interest and has different educational and professional backgrounds which further influence their decisions. Furthermore some stakeholders fulfil more than one role in the process. Kincaid's (2002) table of stakeholders illustrates the relationships between the stakeholders and their respective roles and responsibilities (table 9). Table 9 has been modified to accommodate Australian professional bodies and terminology and to include another stakeholder, that of regulator.

One characteristic of previous research has been that researchers have taken one of the stakeholder perspectives, for example in some studies interviews and case studies have been undertaken with architects or developers and reflect their perspective on adaptation; Arge (2005) examined architects views, Ellison and Sayce (2007) looked at fund manager perceptions. This means that there is inevitably some bias as the researcher is ultimately investigating a view of an issue through only one perspective (Moser and Kalton, 1971).

Table 9 Stakeholders for retrofit of existing commercial buildings adapted Kincaid (2002)

Stakeholder grouping	Description & professional affiliations	Stage where retrofit decisions made
Investors	Pension / superannuation funds, insurance companies, banks, independent investors, professionals who find capital to invest	Beginning / early
Producers	Professional team – Facilities Manager, Quantity Surveyor, Architects, Engineers, contractors, surveyors, suppliers (Royal Institution of Chartered Surveyors, Australian Institute of Architects, Australian Institute of Quantity Surveyors, Australian Institute of Building Surveyors, Fire Engineers, Structural and Mechanical & Electrical Engineers)	Quantity Surveyor / Architect at feasibility stage Design stage Construction stage
Marketeers	Surveyors, stakeholders, professionals who find users for buildings (Australian Property Institute, Royal Institution of Chartered Surveyors)	During design (if selling off plan) and /or construction stage
Regulators	Local Authorities, Planners, Heritage, Building Surveyors, Fire engineers (Planning Institute of Australia, Institute of Fire Engineers)	During design stage (and possibly during construction if amendments are made)
Policy makers	Federal, State and Local Government departments.	Indirect effect on decision-making in retrofit at all stages
Developers	Organisations that combine investment, production & marketing in whole or in part. Professionals from above bodies and others	Beginning / early
Users – Corporate Residential	Large institutional owners and users Individuals Business organisations Occupiers	

Image: Niar / Shutterstock.com

Table 10 **Building retrofit level and title**

Retrofit level	Title
Level 1	Minor
Level 2	Alterations
Level 3	Change of Use
Level 4	Alterations and extensions
Level 5	Demolition
Level 6	New build

2.7 Levels of retrofit

2.7.1 Degrees and types of retrofit

There are different attributes which influence retrofit and also varying levels of retrofit ranging from minor to major. In a study of the London office market, all types of building retrofit were classified into four levels (Kincaid, 2002). Arup and the Property Council of Australia (2008) developed a similar approach with a five level classification, however Kincaid (2002) and Arup and the Property Council of Australia (2008) varied what they included within their respective definitions of retrofit and what is included in minor and major works. Minor works include work such as redecorations and retention of the existing external fabric with minor modifications externally (Kincaid, 2002), whereas Arup and the Property Council of Australia (2008) included installation of blinds, revision of the space plan and redecorations in low level works. High change retrofits include replacing external fabric, changing building structure and reconfiguring internal space (Kincaid, 2002). Complete retrofit is where only sub-structure, superstructure and floor structure is retained and substantial alterations occur to the façade (Arup and Property Council of Australia, 2008). In the same model it should be noted that demolition is included and occurs when no suitable cost effective retrofit can be accommodated; the starting point is after the decision has been taken to retrofit and the remaining choice is about deciding the optimum level of retrofit. Another layer exists where there are different types of retrofit such as ‘within use’ and ‘across use’ or ‘change of use’ retrofits to consider (Ellison & Sayce, 2007). In Wilkinson et al. (2009b) other issues such as the stakeholder perspectives and potential retrofit outcomes were discussed.

Minor works (i.e. the least work undertaken), alterations works (i.e. including revisions to the space plan, redecorations and retention of the existing external fabric with minor modifications externally), change of use (from one land use to another, for instance office to residential), alterations and extensions (major work including reconfiguring internal space, changes to the structure and fabric, services and decorations), demolition and new build were examined (see summary in Table 1).

Figure 4 Conceptual model of influencing attributes in building retrofit and levels of building retrofit

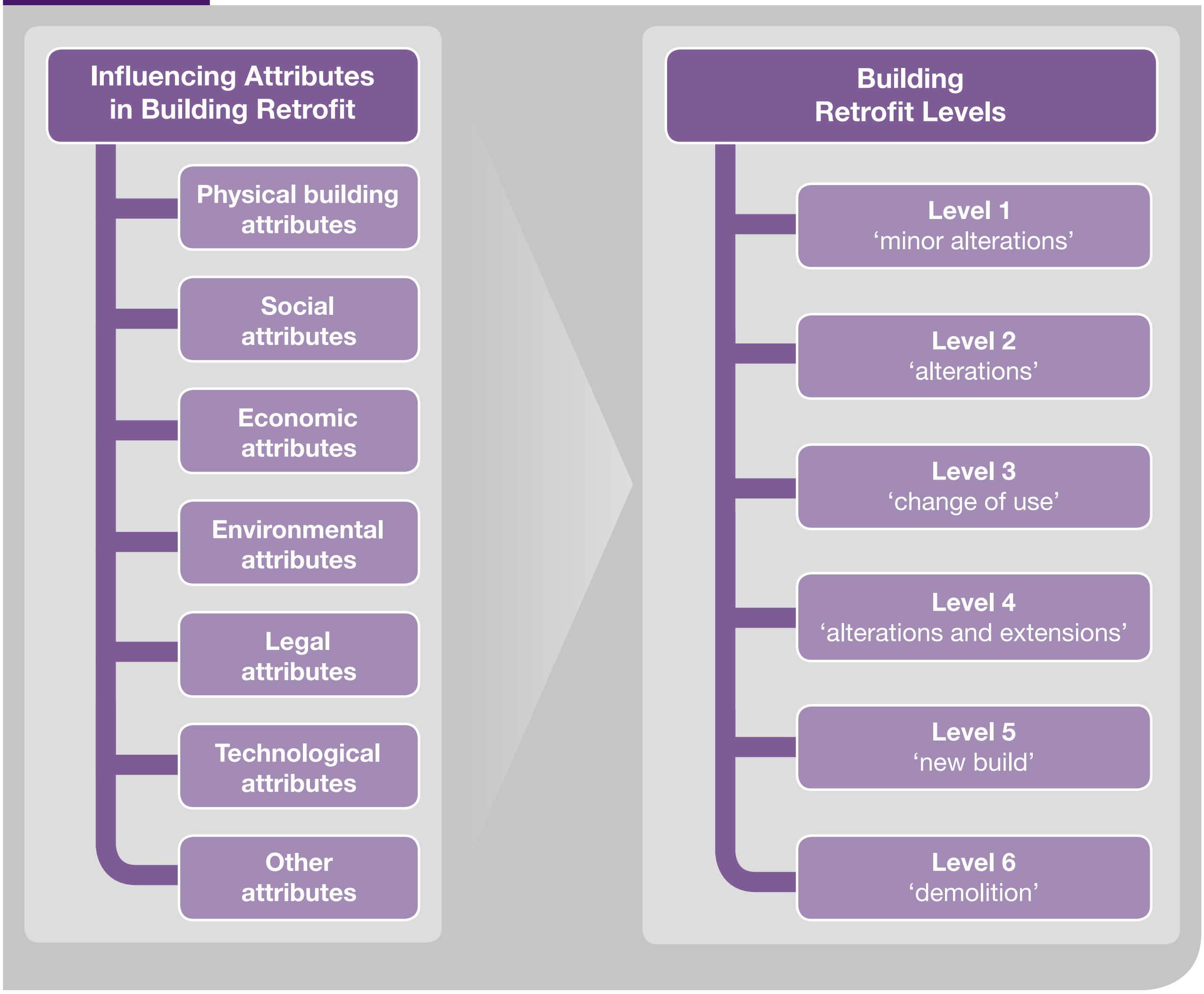


Figure 4 shows the relationship between the influencing attributes identified in the literature and building retrofit events. Each of the seven categories will affect the building retrofit event though not all may be present or influence each retrofit event to the same extent. In the lower half of the conceptual model (figure 4) building retrofit events are grouped into the following outcomes; level 1 'minor alterations', level 2 'alterations', level 3 'change of use' retrofit, level 4 'alteration and extensions', level 5 'new build' and level 6 'demolition'. Although the model may appear rigid the design includes some flexibility and it may be altered as follows; the number of retrofit events entered into the model is variable and can be adjusted according to the circumstances surrounding different buildings, cities or locations. In this model retrofit events and property attribute variables are examined retrospectively to assess their level of correlation.

The building retrofit decision-making model is founded in the work of Chudley (1981) for the most part and to a lesser degree on the works of others (Kincaid, 2002; Langston, 2007; Arup, 2008). It is worth noting that some authors have expressed their concept of decision-making in building retrofit in a written form with a practitioner focus to their notion of building retrofit decision-making (Arup, 2008; Davis Langdon, 2008;MacAllister, 2007). These researchers have a practical focus and wish to develop useful tools that practitioners can adopt to improve their professional practice and the standard of their services to clients. Others have expressed ideas about decision-making issues in building retrofit in the written textual form rather than a conceptual model and come from an academic background (Remøy and van der Voordt, 2006; Douglas, 2006; Highfield, 2000; Kincaid, 2002) and their intent has been to develop robust and reliable thinking and tools to further the knowledge base and to improve practice. The contribution of all the researchers is valuable to the debate about the optimum decision-making in building retrofit.

3.1 Methodological issues and research method

Building retrofit and the associated decision-making process is a complex issue with multiple variables to consider. Previous studies (see Remøy and van der Voordt, 2007; Langston et al., 2007) have confirmed the accurate identification of the factors influencing retrofit can be challenging and relatively subjective. To overcome these barriers this research adopted an innovative approach and compiled a comprehensive database with detailed records of all retrofit events. Therefore this study did not rely on individuals personal preferences although it identified and evaluated a large number of building retrofit events.

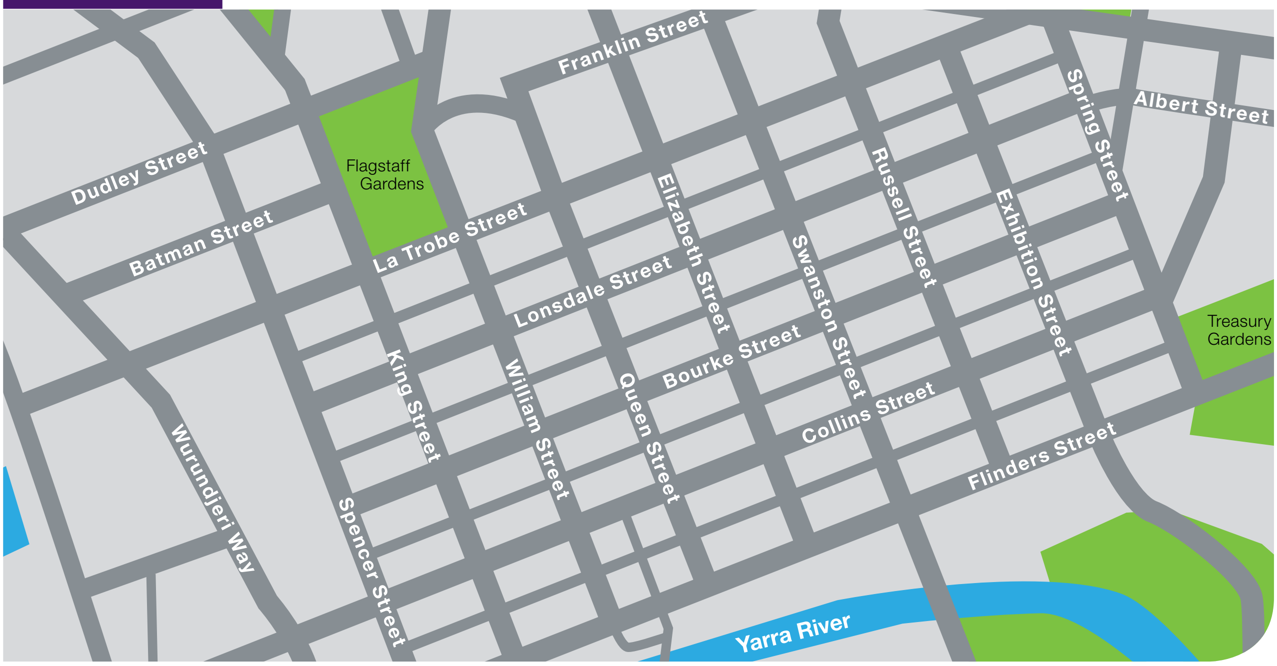
The challenge is manifold, firstly it is to develop a model which is not narrowly based on a limited number of attributes of which the relative importance in retrofit is unknown, except anecdotally. Secondly, it is to avoid expensive, time consuming and complex tools and thirdly it is to avoid potential bias. This paper deals with the first step in the process which is to identify the attributes which are important in building retrofit from non-biased sources.

Previous studies examining the criteria for building retrofit adopted a case study approach based on in-depth analysis of a relatively small sample of buildings (Austin. 1988; Barras and Clark. 1996; Ohemeng. 1996; Blakstad. 2001; Heath. 2001; Ball. 2002; Kincaid. 2002; Kucik. 2004; Arge. 2005; Remøy and van der Voordt. 2007). From these studies retrofit criteria were identified, however the approach is fundamentally different due to the detailed volume of data and the method used. Firstly retrofit criteria were identified and formed the fields for the building attribute database.

A building attribute database of commercial buildings in the Melbourne CBD was assembled and populated from sources including the 'Cityscope' database (R P Data. 2008) and through commercial data produced by the Property Council of Australia (Property Council of Australia. 2007). Building retrofit events were extracted from building permits received by the Building Commission in Victoria with supporting information gathered by visual building surveys. The building attribute database included variables listed above which were coded as physical, social, legal, economic and environmental attributes of retrofit. The risk of an unrepresentative sample was avoided through the adoption of a census approach. Every building retrofit event between January 2009 and July 2011 within the Melbourne CBD is examined and in total 1811 commercial building retrofit events occurred.

The preliminary task was to define the geographic area for the study which is representative on a global scale; this research sought to investigate activity in a well-developed, mature commercial market. The CBD was the first area laid out in Melbourne in 1834 and has been continuously occupied since. In a similar manner to other international cities this area has remained the most mature property market in Victoria with the highest level of demand. The streets within the CBD area are as Flinders Street (southern boundary), Spencer Street (western boundary), Spring Street (eastern boundary) and La Trobe Street (northern boundary) highlighted in figure 5.

Figure 5 **Melbourne CBD street names**



3.2 Principal Component Analysis (PCA)

It is generally accepted that PCA is a reliable, proven method of highlighting dimensions in cross sectional data (Horvath, 1994) with the capacity to uncover, disentangle and summarise patterns of correlation within a data set (Heikkila, 1992). PCA condenses information contained in a number of original variables into a smaller set of new composite factors with a minimum loss of information (Hair et al., 1995) and was used to reduce the dimensionality of office building attribute data relating to retrofit in the CBD between 2009 and 2011. All building retrofit attributes were examined to identify the degree of variance explained with the objective being to identify the highest level of variance explained by an interpretable group of factors. Initially all variables were entered into the PCA to produce a smaller number of components where factors with Eigenvalues exceeding 1.0 were retained. The factors were rotated using an oblique 'Oblim' rotation method with a final result being a table of identifiable factors which includes the loadings of individual building attributes.

1422 building retrofit events occurred between January 2009 and July 2011 in the CBD to commercial buildings for which full address details could be determined. 1275 were 'alterations' retrofits, 89% of all events, which is the second level of retrofit after minor works (see figure 5 above). Assigning meaning involves interpretation of the pattern of the factor loadings and is somewhat subjective (Hair et al., 1995). Following an analysis of the loadings across the factors the minimum threshold was 0.5 as recommended by Tabachnick and Fidell (2001). With the list of each factor containing high loading building attribute variables, the researcher assigned factor names. This analysis examined all events classed as 'alterations' the second most extensive degree of retrofit in the study and coded as level 2.

3.2.1 Procedure – steps 1 & 2

For the retained property attributes the KMO score and Bartlett test are shown in table 11.

Table 11 **KMO and Bartlett's Test**

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.606
Bartlett's Test of Sphericity	Approx. Chi-Square	1621.785
	Df	45
	Sig.	.000

With the KMO of 0.606 exceeding 0.50 and the significance less than 0.05, the PCA was continued. A total of ten property attributes were analysed and produced a ten factor table (5.4). This suggests that four factors of property attributes have had the highest effect on CBD building adaptations between January 2009 and July 2011.

After the initial extraction using 42 variables, the reduced variables retained for 'alterations' retrofit events (level 2) were:

1. Vertical services location
2. Number of Storeys
3. PCA grade
4. NABERS
5. type of construction
6. Green star rating
7. Parking
8. Historic listing
9. Street frontage (metres)
10. Aesthetics

3.2.2 Procedure – step 3

The first heading under initial Eigenvalues shows the variance explained by each of the ten variables (Hinton et al. 2004). Four components explain 69.99% of the original variance. The third section shows the Eigenvalue of each of the four rotated components. Note that as the components are correlated with each other there is some overlap in the variance explained by each factor (Francis, 2007). The total amount of variance explained by the four components cannot be obtained by adding the four Eigenvalues. For the rotated solution the factor loadings are given in the table headed Pattern Matrix (table 13) and correlations are given in the table 13. Table 12 shows the four components for this PCA.

Table 12 Total variance explained PCA 'alterations' retrofit events

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		Extraction Sums of Squared Loadings	Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.162	31.622	31.622	3.162	31.622	31.622	2.859
2	1.479	14.788	46.411	1.479	14.788	46.411	1.414
3	1.358	13.577	59.988	1.358	13.577	59.988	2.072
4	1.001	10.011	69.999	1.001	10.011	69.999	1.127
5	0.949	9.495	79.494				
6	0.755	7.552	87.046				
7	0.520	5.203	92.249				
8	0.395	3.952	96.202				
9	0.232	2.319	98.521				
10	0.148	1.479	100.000				

Extraction Method: Principal Component Analysis.
a When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Table 13 Pattern Matrix[a] for Level 2retrofit events

Property Attributes	Environmental / physical (Factor 1)	Social / physical (Factor 2)	Physical (Factor 3)	Environmental (Factor 4)
PCA grade	0.89	-0.06	-0.02	-0.20
NABERS	0.82	0.33	0.18	0.16
Aesthetics	0.78	-0.28	0.03	0.01
Number of Storeys	-0.63	0.10	0.46	0.07
Historic listing	0.20	-0.76	-0.24	-0.12
Construction type	0.00	0.52	-0.13	-0.22
Parking	-0.31	-0.51	0.37	-0.25
Street frontage (metres)	0.10	0.20	0.96	-0.04
Vertical services location	-0.01	-0.21	0.62	0.03
Green Star rating	-0.06	-0.07	-0.05	0.95

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 9 iterations.

3.3 Data analysis – results

Table 14 **Summary of Level 2 alterations PCA Component Categories**

Component number	Component name	Component attributes
1	**Environmental and physical** (32%)	Property Council of Australia building quality grade (29%) NABERS rating (26%) Aesthetics (25%) Height (number of storeys) (20%)
2	**Social and physical** (15%)	Historic listing (42%) Construction type (29%) Parking (28%)
3	**Physical** (14%)	Street frontage (60%) Vertical services loca-tion (40%)
4	**Environmental** (10%)	Green Star rating (100%)

3.3.1 Component one

The attributes Property Council of Australia building quality grade, NABERS rating, aesthetics and number of stories are all highly or very highly loaded on component 1 (table 13). These variables explain 32% of the original variance where the component one has four attributes, the first three relate to sustainability dimensions (environmental and social) and the fourth one relates to the size of the property in terms of height (i.e. physical attributes). It is possible to refer to these attributes as ‘environmental and physical’. Aesthetics is loaded on component one and relates to building appearance indicating that buildings having a poor appearance, i.e. outdated or worn, are less likely to be adapted. The final variable ‘number of stories’ is strongly and negatively loaded and relates to physical dimensions of the building.

3.3.2 Component two

Three attributes were loaded high on component two; historic listing, construction type and parking (table 14) and they explained 15% of the variance. In this component the attributes were influenced by social and physical factors. Historic listing applies to the social characteristics or values of the property. The type of construction and the provision of parking relates to physical attributes. Historic listing limits to some degree the level of work which any owner or user can undertake. The type of construction form being either skeleton frame or load bearing has some bearing on the flexibility and ease and the cost of building alterations. Parking is negatively loaded.

3.3.3 Component three

Two attributes street frontage (building width) and vertical services location are very strongly and moderately loaded on component three and explained 14% of the variance (table 14). The attributes can be collectively described as physical and relate to the size and dimensions of the building and also the level of flexibility in terms of space configuration.

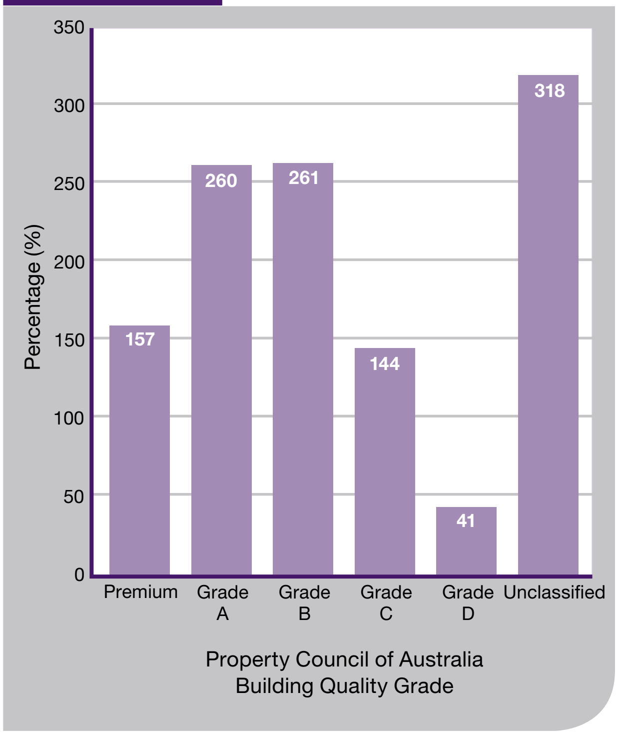
3.3.4 Component four

One attribute Green Star rating is very strongly loaded on component four and explained 10% of the variance (table 13). The attribute measures the provision of an environmental rating for a floor or a building. Green Star shares many similarities to the UK BREEAM tool and the US LEED tool. The variable is described as environmental. Table 13 summarises the main PCA component categories and the component names ascribed by the interpretation.

3.4 Discussion of 'alterations' retrofits

'Alterations' retrofits are those involving the second level of works. The highest number of events featured in this category, illustrating that owners of Melbourne office buildings were more likely to engage in this type of retrofit than any other from January 2009 to July 2011, and this number of retrofit events indicates reasonably high confidence in the market. Although it is the period immediate following the Global Financial Crisis of 2008, 1422 events occurred and this is about 46 events per month. 'Alterations' retrofits are typically undertaken when leases expire and new tenants move in or to refresh spaces to attract new tenants in order to maintain the low vacancy rates.

Figure 6 **PCA grade and number of alterations retrofits**



3.4.1 Component one – environmental and physical

This component is interesting in that a clear environmental attribute, NABERS rating features for the first time in a PCA of building attributes and retrofit in the Melbourne CBD. The inclusion marks a change from the previous CBD study conducted by the researcher (see Wilkinson et al .,2010; Wilkinson and Reed, 2011) and a growing maturation in the commercial property sector with regards to sustainability and retrofit. The recently published report Building Better Returns (Newell and McFarlane, 2011) confirmed increasing uptake in sustainability measures in Australian office stock and that increased capital value and rental levels were evident in this greened stock. 46% of the retrofitted buildings had a NABERS rating in this study which is a very proportion and suggests that increasingly levels of activity are occurring in the sector of environmental upgrades.

The attribute most strongly loaded in component one is Property Council of Australia building quality grade. The results illustrate that with the majority of retrofits the ongoing maintenance or enhancement of the quality of the building (i.e. Property Council of Australia building quality grade) is very important.

Figure 6 below shows that the better quality stock is retrofitted more frequently than lower quality office stock. The two top grade, Premium and grade A accounts for 35% of retrofit activity. Whilst grade C and D accounts for 12 and 3% respectively. The amount of retrofit to the lower grade stock shows a decline on the activity levels and market share of retrofit previously reported in Wilkinson & Reed (2011) and Wilkinson (2011). It appears that the performance gap between the top and lower grade stock is widening further. There was an identified relationship between Property Council of Australia building quality grade, environmental rating, aesthetics and size. With all other variables being equal generally the larger the building and the better the specification in respect of building services and equipment, the higher the Property Council of Australia building quality grade. The grading matrix classes Premium as the best office grade, followed by A, B, C and D. Some office buildings are not be graded in the system and are categorized as 'ungraded' The inclusion of Property Council of Australia building quality grade and its highest loading is confirmed as Premium, Grade A and B stock has higher rates of retrofit than Grade C and D stock. Further examination of the data investigated and the type of retrofit by Property Council of Australia building quality grade is shown in figure 6.

Table 15 **All retrofits by Property Council of Australia building quality grade (all grades)**

PCA Grade	Level of retrofit minor works	Alterations	Change of use	Alterations and extensions	Total by Grade
Premium	0	157	0	9	166
Grade A	0	260	0	23	283
Grade B	0	261	1	21	283
Grade C	0	144	0	13	157
Grade D	0	40	0	4	44
Unclassified	1	411	39	24	475
Total by retrofit type	1	1273	40	94	1408

When all works undertaken are considered, the building grade was not significant. From Premium to unclassed stock the percentage of work undertaken over the timeframe was fairly evenly distributed (see table 15 above). For example with 'alterations' retrofits the figures for Premium through to unclassified stock were 95%, 92%, 92%, 92%, 91% and 87% respectively. No change of use retrofit occurred in Premium, Grade A, C or D stock and this type of retrofit is very rare in the CBD. After 'alterations' the second most likely type of Premium grade retrofit was 'alterations and extensions' (5%) and no minor work was recorded. Owners of this stock elected to undertake alterations retrofits work rather than any other type to retain the classification 'Premium'. A similar profile emerged with A and B Grade stock where the preference is for alterations to retain the level of quality and tenants within the building. With the C and D grade stock, there is much less work done overall; although the profile of retrofittype is similar to the higher grade stock.

Owners of lower grade stock were less inclined to spend or invest in adaptation. C grade stock has the highest pubilshed running costs on a per metre squared basis and is a good sector to target reductions in greenhouse gas emissions through sustainable retrofit either through upgrades to the envelope or services. It would seem reasonable that Premium and A grade stock would have the highest running costs as this stock has the highest specification in respect of building services. The Property Council of Australia (2007) survey of building owners reported the cost in use profiles across all grades which showed operating expenses for Premium and grade A office buildings were \$62.11 per square metre, Grade B \$54.17 per square metre, Grade C stock was highest at \$73.35 per square metre and no data available for D Grade and ungraded stock. It is considered that C grade stock is likely to have outdated building services which are not serviced regularly and that the buildings are likely to be less well maintained and not designed with energy efficiency as a priority (Property Council of Australia 2007). D Grade stock received the least amount of retrofit work where owner motivation is to avoid increasing vacancy rates and rental returns decreasing and to maintain code compliance.

As with previous studies into the relationship between retrofit and building appearance (Wilkinson and Remøy, 2011; Wilkinson, 2012), buildings which are more aesthetically pleasing underwent more adaptations (figure 7). Buildings ranked most very attractive accounted for 30%, those ranked attractive 38%, third ranked 17%, fourth ranked 13% and least attractive (ranked five) accounted for 2% of works. These figures map very closely to Wilkinson's 2011 study, showing a very slight increase in the percentage of more attractive stock undergoing retrofit and this may reflect a slightly tougher economic climate in this later study.

Figure 7 Alterations retrofit and aesthetics

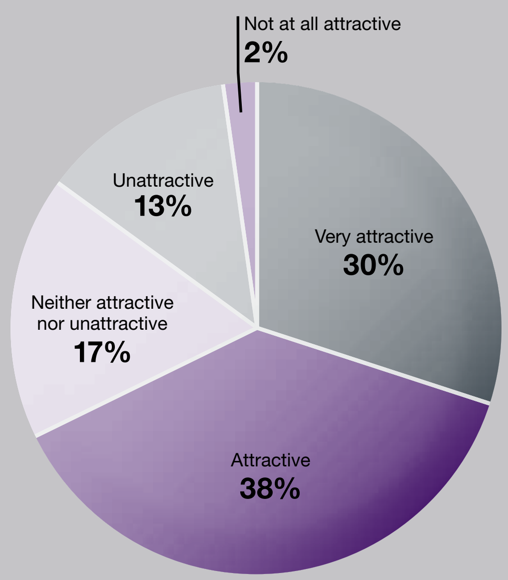
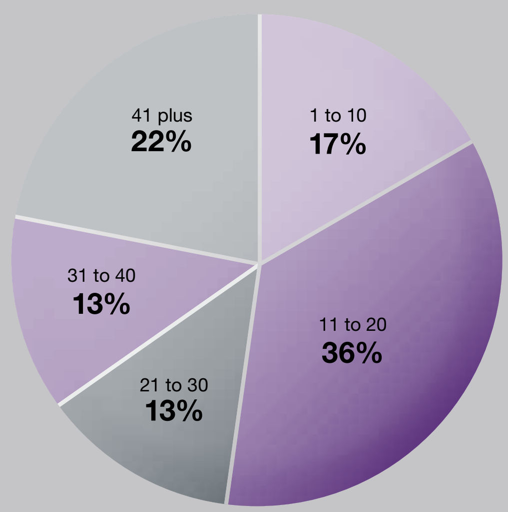


Figure 8 Alterations retrofit and building height (number of stories)



Two studies found that building height was an important factor in retrofit (Povall and Eley in Markus ,1979; Gann and Barlow, 1996) and the inclusion of this attribute in the PCA confirms that finding in the Melbourne study. Figure 8 shows the percentage of 'alterations' retrofits by number of stories, where buildings were grouped into five categories of ten stories. 53% of works are undertaken to buildings below 20 stories. The amount of work tails off from 21 stories to 40 stories and then increases in the 41 storeys plus group. It is apparent the biggest percentage if works occur to medium rise buildings where the turnover of tenants

A further breakdown of the data by building age and building height shown in figure 9 shows that the majority of retrofit to skyrise stock that is 41 stories and higher occurs to stock aged 11 to 20 years and 31 to 40 years respectively. Work to stock aged 60 years plus is exclusively to buildings of less than 20 stories height. The majority of work to mid rise stock, that is 11 to 20 stories occurs to older stock aged 31 to 50 years.

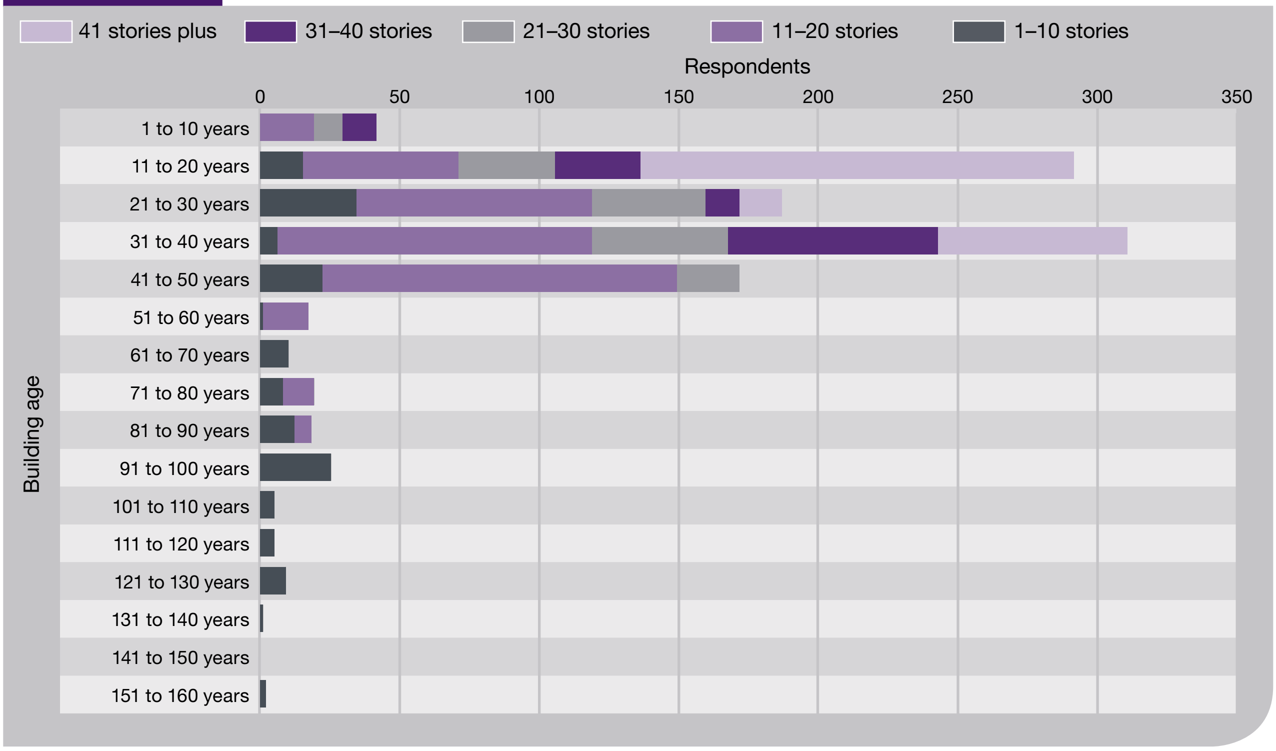
3.4.2 Component two – social and physical

The third component named 'social and physical' contained three variables: historic listing, construction type and parking. Historic listing and construction type are correlated where listed buildings are more likely to have a traditional load bearing masonry construction of either brick or stone. Ball (2002), Bullen (2007) and Snyder (2005) all noted heritage listing affects retrofit. The most obvious impact is that restrictions are placed on owners with regards to the extent of work and the materials which must be used. Buildings undergo more retrofit in the early to mid-stages of the life cycles when they are more likely not to be listed. At the later stages of the lifecycle most commercial office buildings appear to reach a stage whereby it becomes increasingly difficult and expensive to achieve fitness for current purposes. 74% of the retrofitted stock in this study was not listed and it is clear that a greater amount of retrofit occurs to the unlisted sector of the stock.

Construction type here denotes the structural system which supports the building. In this study 93% of the retrofitted buildings had a steel or concrete skeleton frame and the remaining 7% were constructed with a traditional load bearing masonry wall construction. Skeletal frame construction does allow a greater degree of flexibility in retrofit in terms of the capacity to extend the building vertically (Arge, 2005) and to sub divide floor space internally. Whilst the majority of the works were of a more minor nature the results shows a preference for retrofitting buildings which have inherent flexibility in the construction type.

The third attribute loaded in this component is parking. Historically in Melbourne car parking has been a premium in office building specifications typically attracting higher rental and lower vacancy levels, though this may change as sustainability criteria become more important in office buildings. In this analysis 82% of the retrofitted buildings had some parking provision on site which is a high percentage and reflects the stock on the CBD. Whilst is likely that higher quality stock would have a greater amount of car parking provision than the lower quality stock, retrofit work is largely undertaken to stock with this amenity. Significantly if there is a move to reduce car parking provision within commercial office stock to enhance sustainability there is a reasonable amount of car parking space which would lend itself to change of use retrofit to other land uses. The discussion above shows that parking can be interpreted as an economic attribute (increasing rental values) or a physical attribute (space within the building with potential for other uses) or even an environmental attribute (environmental rating tool value minimum levels of car parking more highly). The way the attribute is interpreted depends which aspect is focused on and is this instance for interpretation purposes when coupled with historic listing and construction type interpretation in terms of the physical aspects is logical.

Figure 9 **Alterations retrofit by age and building height (number of stories)**



3.4.3 Component three – physical

Component three contains two attributes; street frontage and vertical services location and is labeled 'physical' because the attributes are related to physical attributes of buildings. Fifty nine per cent of all 'alterations' retrofits occurred to buildings of 40 metres width or less which was noted in an earlier CBD study (Wilkinson & Reed, 2011). There is a preference to adapt buildings with smaller width and these properties are either more versatile and or have greater flexibility to accommodate retrofit.

The second attribute is *vertical services location*. Previous studies noted the vertical services location was an important retrofit consideration (Gann and Barlow, 1996; Snyder, 2005; Szarejko and Trocka-Lesczynska, 2007). Services cores in commercial buildings can be located centrally, offset towards the front or rear of the building or in dual/multiple locations. Buildings with large floor areas tend to have their services cores in more than one location and this adds greater flexibility in space planning and sub-division of floor space (Arge, 2005). Conversely the least flexible location for the vertical services is at one end of a narrow plan floor plate, where sub-division of the floor is more challenging as valuable rentable floor space is given up for non-rentable corridor space to provide access to the leased tenant spaces. The *vertical services location* affects the ability to sub-divide the space, for example it affects how services can be delivered to various parts or areas of the building (Ibid.). In this dataset, 51% of all retrofits occurred to buildings with centrally located service cores which give the greatest amount of flexibility in the sub-division of floor plates (Ibid.).

Buildings having multiple services core locations accounted for 34% of all retrofits, confirming buildings with greater flexibility of layout undergo high rates of retrofit. Where services are located elsewhere in the floor plate a far lower rate of retrofit takes place and account for 15% of all retrofit. It follows that depending on the size of the floor plates and whether the demand is for large or smaller floor areas, the location of the services core can affect how easy and costly retrofit might be. This is a design issue, with only major alterations having the potential to relocate vertical services cores. Most retrofit projects have to work within the original configuration and location of services cores because the costs of relocating vertical services are extremely high. The property attribute *vertical services location* is aligned with the flexibility potential of the building and was highly ranked by Arge (2005) in her office building retrofit study.

Figure 10 **Number of alterations retrofits and building width (in metres)**

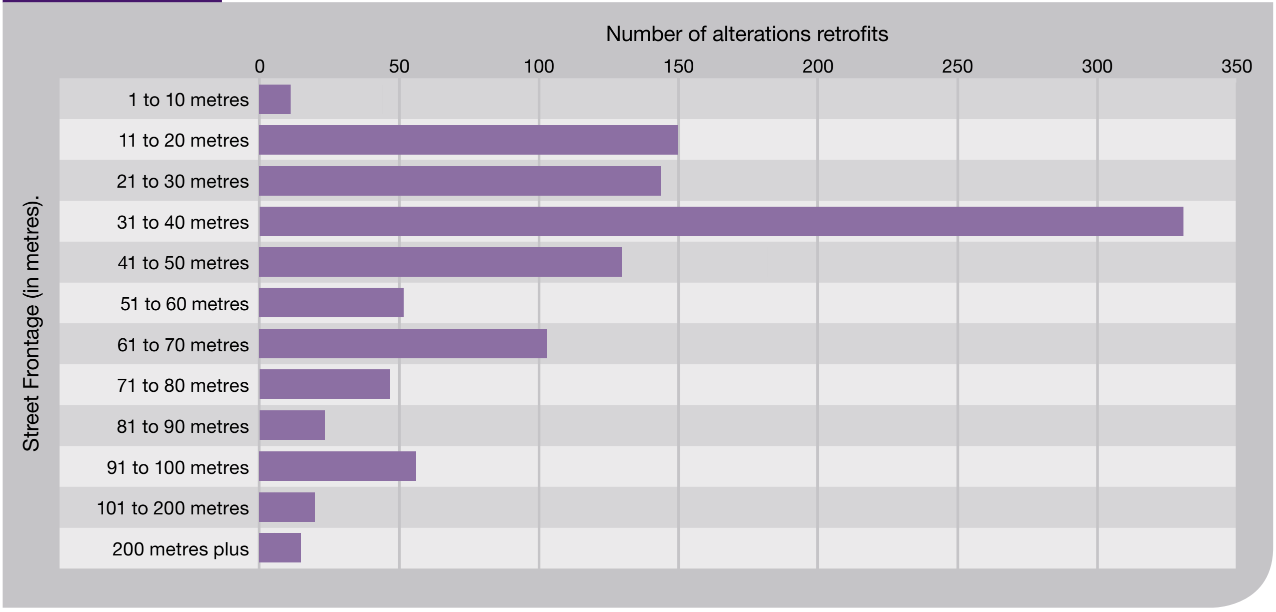
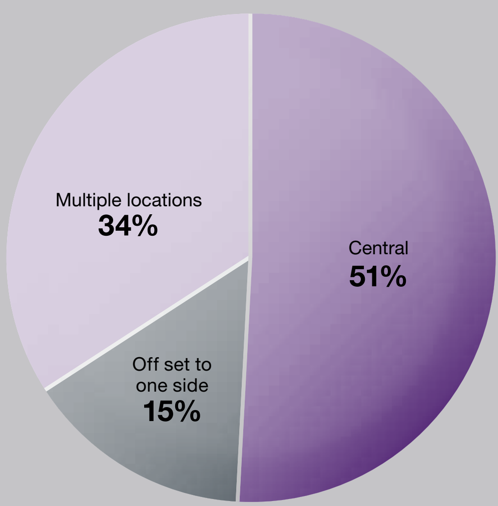


Table 16 Alterations retrofits by building width (in metres)

Street Frontage	Number of 'alterations' retrofit events
1 to 10 metres	11
11 to 20 metres	150
21 to 30 metres	143
31 to 40 metres	332
41 to 50 metres	131
51 to 60 metres	51
61 to 70 metres	101
71 to 80 metres	47
81 to 90 metres	23
91 to 100 metres	56
101 to 200 metres	20
200 metres plus	15

Figure 11 Location of vertical services



Source: Xxxxx Xxxxxxxxxx

3.4.4 Component four – environmental

The final component has a single attribute, Green Star rating which is very strongly loaded on the factor. There has been an increasing awareness and uptake of sustainability tools and measures over the last 5 years within Australia and it is possible that environmental attributes are becoming important in retrofit. Previous studies have not found environmental attributes were important in commercial building retrofit (Wilkinson and Remøy, 2011; Wilkinson, 2011). When the data is analysed 98% of the retrofitted buildings did not have a Green Star environmental rating. Comparing the percentage of buildings with NABERS ratings (in component one) it is clear that far more owners and occupants and adopted this form of environmental rating tool in Melbourne. In November 2010, Mandatory disclosure of energy consumption became compulsory and this has triggered an increase in the number of rated buildings. The result of the NABERS being loaded strongly in component one is clear evidence of the power of regulatory tools influencing the market in terms of sustainability. Green Star, on the other hand, is a voluntary tool that rates a much broader range of sustainability attributes and its market penetration is far lower. However it is significant that the Green Star rating tool has featured in the PCA, albeit in a single attribute component because hitherto this had not been the case (Wilkinson and Reed, 2011).

3.5 Findings and research questions

This section of the report sets out the key findings of this stage of the research and addresses the two research questions posed in this study.

When all building permits were analysed, commercial buildings accounted for 55% of all work in the CBD, followed by retail at 29% therefore the City of Melbourne are targeting the sector which currently is the most active in the CBD and therefore has the potential to deliver the highest level of emissions reductions.

The 1272 alterations retrofit events only were analysed in the PCA because according to Jackson (2003) at least 100 cases or five times the number of attributes are required to undertake a reliable PCA. As there were 42 attributes to analyse the minimum sample size would be 210 and only the alterations events satisfied this criteria.

Table 17 Total events Melbourne CBD 2009 to 2011

Retrofit level	Total number of events January 2009 to July 2011
Minor works	1
Alterations	1272
Change of use	3
Alterations and extensions	123
New build	17
Demolition	6

The results of the alterations PCA clearly shows that ten attributes group into a four components and account for 69% of variance in retrofit. This is a reasonable degree of importance for a small number of attributes and the 32 attributes which were progressively removed account for the 31% of importance in retrofit.

The results of the alterations PCA clearly shows that two environmental attributes, the rating tools NABERS and Green Star are important in building retrofit at a minor level and this is a major change from the earlier study covering the period 1998 to 2008 (Wilkinson & James, 2012). As with the previous study, the property attributes do not group together in a neat pattern, for example physical attributes pair with environmental and social attributes in one component. The earlier PCA based study concluded that it was possible that previous studies which looked at decision making in building retrofit using a smaller number of case study projects had simplified the groupings of attributes based on logic rather than a quantitative process. The PCA overcomes this, using a quantitative objective methodology and a large sample to determine which attributes account for the most variance in retrofit and how they group together.

Physical attributes featured in three of the four components and show that the physical attributes remain important, however other attributes such as social and environmental are included. Whilst economic attributes did not feature greatly it is possible to interpret the Property Council of Australia building quality grade as an economic attribute as well as an environmental one. Similarly the provision of parking and an historic listing could enhance a building's capital and rental values.

For stage one, the research questions were;

a) are environmental attributes are important in office retrofit?, and;

b) where is the sustainable office retrofit market trending?

On the basis of the analysis here, environmental attributes are shown to be important in alterations retrofits in the Melbourne CBD between January 2009 and July 2011. For example, the NABERS rating tool accounted for 26% of the importance within component one which explained 32% of the original variance. In the fourth component the environment attribute Green Star accounted for 100% of importance within the component which explained 10% of the original variance.

The second research question asked where the sustainable office retrofit is trending and on the basis of this analysis it would appear the Mandatory Disclosure legislation is having an effect whereby more buildings are now rated. It is likely that this will continue as more leases expire over the coming 4 year period and the opportunities for sustainable retrofits present themselves to building owners.

4.1 Research design and methodologies

This section sets out the nature of the research and the way in which the research design evolved. The advantages of the data collection techniques adopted are discussed along with their respective limitations. The way in which the data collection techniques enabled the researcher to meet the research aims and objectives are identified. The research population and the sampling techniques are also discussed. Furthermore questions of reliability and validity of the research design are addressed. As previously stated this part of the research project had two aims;

- To gain a deeper understanding of the improvements made to existing office buildings in the 1200 Buildings Program in Melbourne, Australia.
- To undertake a comparison of current practice to identify similarities and differences in approach to retrofit in the 1200 Buildings Program.

4.2 The nature of this research

The research methodology was designed to ensure the research aims were met. Clearly, from the outline of the nature of the research problem and the research questions identified in section two, this research project embodies the characteristics associated with qualitative research (Silverman, 2000). The main features of qualitative research are a preference for qualitative data with the analysis of words and images rather than numbers, featuring observation rather than experiment. This type of research has a preference for meaning rather than behaviour, a rejection of natural science as a model and, finally, a preference for inductive, hypothesis generating research (Ibid.).

This research involved the analysis of words. The research examined the research population's current practice regarding sustainable commercial retrofit as practised by participants of the 1200 Buildings Program.

Research aim two was to undertake a comparison of current practice to identify similarities and differences in approach to retrofit and the introduction of sustainability measures. This research is exploratory research to identify what is undertaken with regards to sustainability when commercial property is retrofitted, and this aim was best achieved through a content analysis of the published case studies of completed 1200 Buildings Program projects. The City of Melbourne provides case study exemplars of the buildings within the 1200 Building Program on its website[3]. Some data was coded and analysed using SPSS software. The results were interpreted through a process of triangulation with the literature and previous Melbourne CBD research into retrofit practices undertaken by the primary researcher.

3 http://www.melbourne.vic.gov.au/1200buildings/CaseStudies/Pages/CaseStudies.aspx

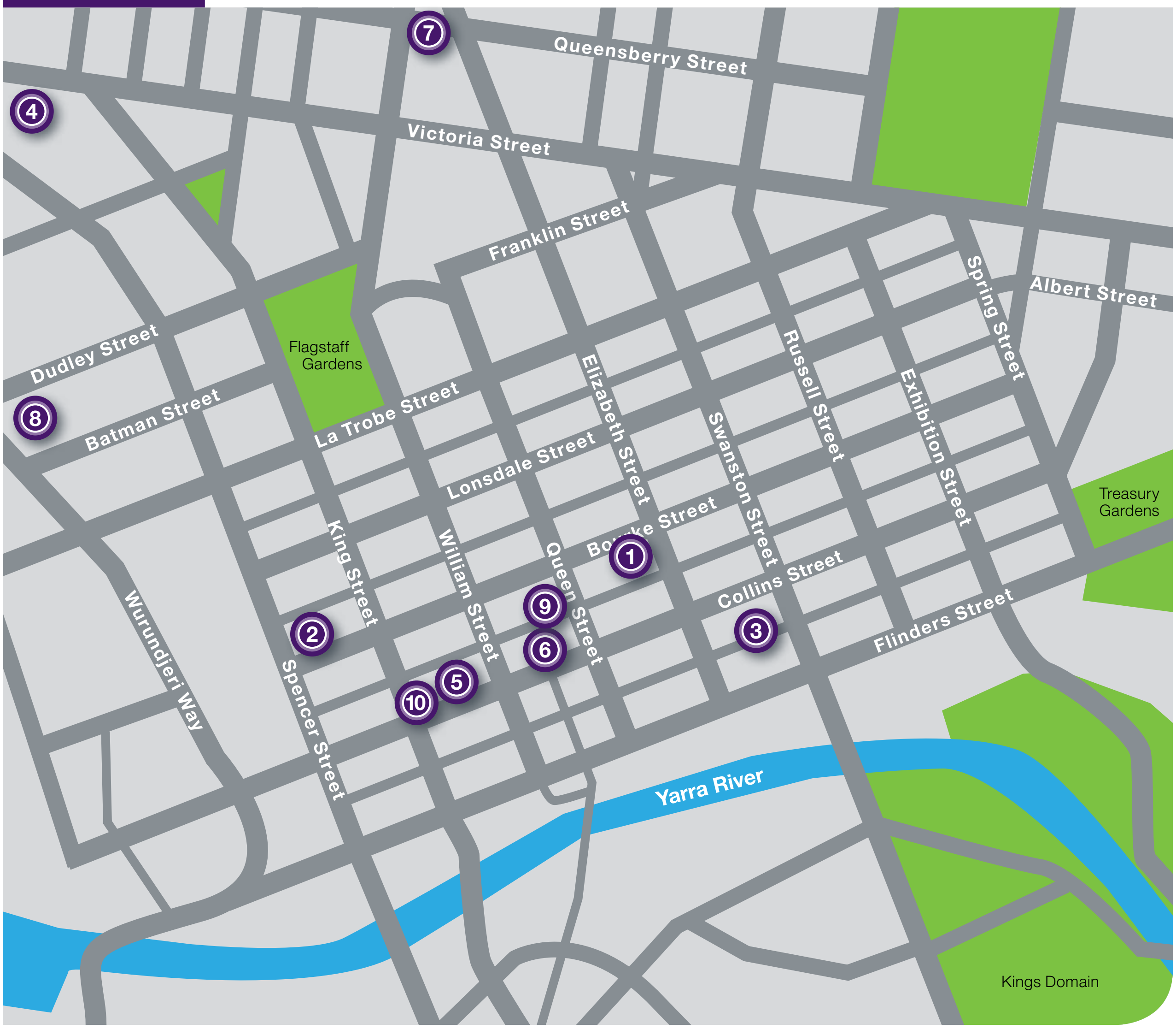
4.2.1 Case study research and the research sample

Case study research can be said to be either exploratory or explanatory (Robson, 2003). In this instance the cases are the building retrofit projects undertaken within the 1200 Buildings Program. The data relates to the retrofit measures undertaken with regards to sustainability and the property attributes of the buildings. The analytical strategy adopted in this research is partially explanation building and partially pattern matching with previous patterns of building retrofit practices in the Melbourne CBD. The questions of internal and external validity are addressed as follows. Given that the primary purpose of the case studies was to observe and describe what measures had been undertaken, internal validity was not relevant (Trochim, 2006).

External validity issues centre on the representativeness of the cases and how they can be extrapolated to the wider population. In this study, all the cases posted on the official City of Melbourne 1200 Buildings Programme website as of 28th September 2012 were used in the analysis. In this way the research has external validity because all cases are considered. The analysis is therefore a census of all the projects completed to date within the program for which data was available. There were ten projects in total. Sampling was not an issue in this case and the findings are representative of the projects completed to date. The location of the 10 cases evaluated in this report is shown in figure 12 below.

An overall description of each of the ten cases is provided in the first part of this analysis followed by a comparative analysis and triangulation with previous studies to identify whether any patterns can be identified.

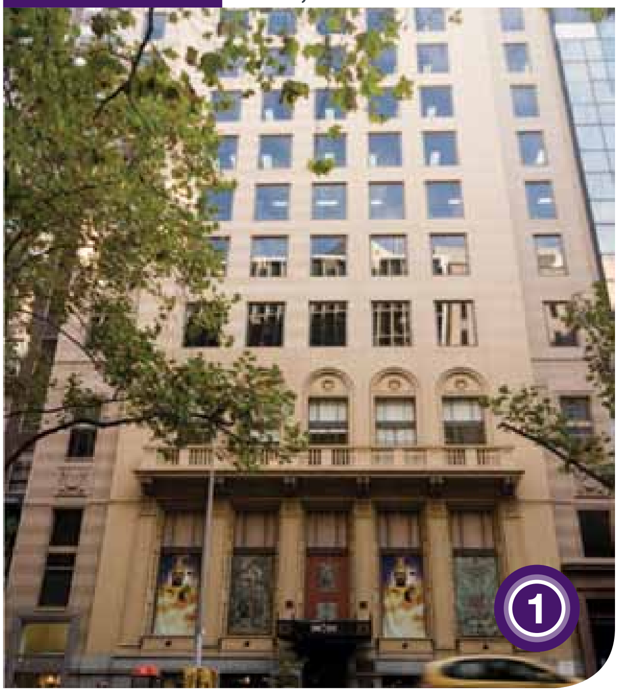
Figure 12 **Location of numbered 1200 Buildings Program Case Studies**



4.3 Case 1 – 131 Queen Street

Originally constructed in the early 1900s, 131 Queen Street underwent a number of retrofits including two major ones during the 1930s to 1950s where eight new floors were added (vertical extension) and the facade was rebuilt in 1955. The net lettable area (NLA) comprises 5830m2 of space and accommodates office use, a Buddhist art gallery and cafe, a turf accountants bar and a restaurant. Eleven owners comprise an owner's corporation which may have made decision making in respect of the retrofit complex and more time consuming. The retrofit was undertaken over a three year period from 2008 to 2011 and predates the Mandatory Disclosure legislation at commencement. The total costs of the project were $1.5 million and savings of $50,000 per annum were estimated as a result of the energy saving measures introduced.

Figure 13 **Front elevation 131 Queen Street, Melbourne**



4.3.1 Objectives

a) To make safety and essential services code compliant,

b) To upgrade to a green building, aiming at 4 to 4.5 NABERS rating,

c) To significantly reduce running costs by focussed on preventative maintenance.

4.3.2 Retrofit features

- Sealed roof membrane,
- High efficiency chiller,
- Variable speed drive (VSD), air handling unit (AHU),
- Economy cycle,
- Digital Building management system (BMS),
- Award winning rooftop garden,
- new fire panel and HVAC system, and
- installation of motion sensors and T5 light fittings and globes in most common areas.

Existing water consumption for the building is low and was not addressed in this retrofit. In addition a waste program is limited by the owner and tenant structure of the building.

Social sustainability aspects are covered in the provision of a roof top garden for building occupiers. The garden mitigates against the urban heat island effect, reduces storm water run-off, insulates the upper floor of the building as well as providing social space.

4.3.3 Challenges

Perceived problems were poor quality air conditioning which had not been adequately serviced or maintained. This was compounded with the need to get all eleven owners to agree to measures and costs, where some had undertaken upgrade independently they were reluctant initially to commit further funds to the property. Value for money was important for the owners. This negotiation stage took a year to complete and was helped with a $500,000 grant from the Australian Government from their Green Building Fund. It is possible that this project would not have been completed, either to its current standard, or at all, without the financial assistance which was a third of the total costs.

Work was completed over 10 months and a requirement of the grant was the work should be completed within 12 months. To minimise disruption to tenants work was carried out at night and on weekends, which drove up costs. In addition access to the property for contractors was from the street entrance only.

4.3.4 Outcomes

1 A 40% reduction in energy costs are predicted, the owners are waiting for a 12 month period to lapse before they can quantify the annual savings accrued and thereby release the final 20% stage payment of the Green Building Grant.

2 The green roof top is much valued and used by the occupants.

3 Savings of $50,000 per annum are anticipated with the new services requiring less maintenance.

4 The key issue with this project was the complex ownership structure.

4.4 Case 2 – Alto Hotel (636 Bourke Street)

636 Bourke Street involves the transformation of a heritage building into a low carbon emissions hotel. Designed in a 'neo-Baroque' or small scale 'Palazzo' style, it was built mostly of brick, with a granite and bluestone façade and floors of New Zealand kauri pine. The building was substantially renovated and enlarged towards Little Bourke Street in 1981. It was sold in 1999 to the current owners, who built a new six storey structure at the northern end of the building in 2005 and redeveloped the original section on Bourke Street. The building is six storeys high with a floor space of 2800 m^2, with each floor plate being 480 m^2. High buildings on the eastern, western and northern sides protect the building. The southern façade retains the original windows. The new building opened in February 2006. Although many of the early architectural features have disappeared, the building is considered to be of State significance and placed on the Heritage Register in 2005.

4.4.1 Objectives

a) To develop an environmentally efficient building, in the use of energy and water,

b) To minimise noise transfer in and around the building.

In 2005, NABERS and Green Star were not available and the owners adopted two other energy and water efficiency measures. Firstly, an annual Earth Check audit under the auspices of Green Globe, which provides a certification program. The Earth Check Program was developed by the Australian government-funded Sustainable Tourism Cooperative Research Centre and is used widely in the tourism industry. Secondly there is an annual CO_2 audit under the auspices of the Carbon Reduction Institute. This was established in 2008 for the purpose of promoting awareness and action on climate change and provides a 'No CO_2' certification programme for member organisations. This programme is used widely in the tourism industry.

4.4.2 Retrofit features

- Insulating the building to substantially reduce the heat / noise transfer.
- High star rating HVAC inverters, with sensor controls.
- Heat as required gas water.
- Hot water reticulation system.
- Low flow taps and showers.
- Fluoro or LED lamps.
- Replenishable dispensers in hotel rooms for guest complimentary toiletries.
- Organic waste and frying oil disposal for conversion to bio-diesel fuel.

Figure 14 **Front elevation 636 Bourke Street, Melbourne**

Given that each room has its own independent inverter system for heating and cooling there is no need for a central BMS. The hotel has a 100% green energy acquisition policy and is seeking to become zero carbon.

4.4.3 Challenges

With this retrofit, the innovative construction techniques required to provide substantial heat and acoustic insulation which was unfamiliar initially to the building contractors was the biggest challenge.

4.4.4 Outcomes

1. Energy consumption per guest has been reduced to 36 Mj/day, 78% better than best hotel practice.
2. Water consumption is 123 litres/day per guest which is 68% better than best hotel practice. Economics savings from reduced water use and water heating costs is significant.
3. The green attributes of the hotel make it attractive to guests scoring well in terms of social sustainability.
4. Maintenance costs may be higher than previously.
5. The owners believe that energy efficiency of the building fabric is paramount and should be addressed before the services installations are changed.

Further work is planned to use solar power to heat the commercial kitchen's hot water systems. There is insufficient roof space to provide hot water for the whole building.

4.5 Case 3 – 247 Flinders Lane (Ross House)

Built in 1897 as a six storey warehouse and heritage listed, Ross House has an NLA of 2120 m^2. The six storey office building consists of a basement car park, a small retail shop on the ground floor, five office floor levels and a roof plant room. The building was designed as a brick structure using a Romanesque style, with brick arcades, metal oriel windows and parapet colonnade. The building was converted to offices in 1931. In the mid-1930s, the Flinders Street half of the building was demolished and new offices built. The Flinders Lane building was retained and named Royston House. Ross House, as it was re-named, opened in 1987. The building was purchased through a grant from the R.E. Ross Trust by the Ross House Association, which offers low rent to tenants; mostly small, independent community and self help organisations committed to social justice and environmental sustainability.

Figure 15 **Front elevation Ross House 247 Flinders Lane, Melbourne**

In the last retrofit (1985 to 1987) all systems were upgraded. The HVAC was changed from a central system to individual units. An Environmental Management Plan (EMP) is used to identify and implement retrofit works over time as funds become available. The retrofit may run over a 4 year program due to funding issues. In addition heritage issues have to be considered throughout and the Conservation Management Plan covers these aspects. The 'low hanging fruit'; that is measures most easily undertaken and cost effective have been implemented from the EMP.

One issue is airtightness as the 1901 building fabric is leaky. The HVAC has reached the end of its life-cycle and needs replacing however funds are not available. Switches need to be positioned so that individual tenants' energy loads can be determined. Water consumptions patterns were already very efficient and, due to financial restrictions and prioritisation of other measures, no further water efficiency measures were required. Waste separation is encouraged in the building with separate bins for recycling waste. The work undertaken by the tenants of Ross House mean that there is a high degree of social sustainability associated with the property.

4.5.1 Objectives

- To overhaul all systems, and to bring the building to a minimum NABERS 4 star level.

4.5.2 Challenges

The key challenge with Ross House is financing the retrofit and the association is seeking grant funding for the $500,000 required. The associated challenge is then to provide the optimum environmental benefits at an affordable cost.

4.5.3 Retrofit features

- Installation of time-clocks for each instantaneous boiling unit.
- De-lamping about 50 existing T8 twin light fittings.
- Installation of light sensors.

4.5.4 Outcomes

To date no outcomes are listed on the website for Ross House. The retrofit was planned for 2012.

4.6 Case 4 – 490 Spencer Street

This example shows the efficiency gains made by reducing the heat load in an older small office building prior to upgrading the mechanical systems. The property is a two storey office block at the north end of Spencer Street. It was built in the 1980s, of tilt-slab construction with no insulation, and was dominated by large west facing glass windows and a grey rendered concrete façade. The HVAC system was a reverse cycle centralised package, with two units cooling and heating the two floors separately. Tenant comfort was achieved by using large amounts of energy though the HVAC.

The decision making for the retrofit comprised three stages. The first step was to undertake a thorough and holistic investigation of the building to understand any performance problems. The unique attributes of the building were identified; particularly good aspects. This revealed the back and bottom of the building were surrounded by concrete; producing a 'cave' which had potential. The limitations were many ventilation leaks and no insulation. Stage two determined how much energy could be retrieved from zero cost sources. Modelling indicated that the owners should be able to obtain 50% of energy needs from other sources: using outside air as an air conditioning economiser and air trapped in the ceiling cavity for heating in winter. Continuing to lower energy use will be continued– by introducing low energy computers and reducing the number that are on at any one time, more efficient switching, providing an individual workstation power-board so all power is connected and one switch turns it off. The aim is to make 'no regrets' changes that are justified on economic grounds alone. The owners do want a high tech building because they believe it removes the chance for occupants to interface with the building and they lose ownership over energy saving efforts. Occupant engagement is critical in achieving the educational benefits of green buildings. Stage three is to reduce energy demand and install a HVAV system to replace the current one.

The retrofit commenced in mid 2009 with the tenants in occupation. The owner believes a combination of a practical architect, a focus on engineering and aesthetics and highly qualified trades-people was vital to the success of the project. Effective cross disciplinary communication was also critical. A survey showed where the leaks were occurring and these were plugged. R3 insulation was retrofitted above suspended ceiling tiles because the cost of replacing the roof (with the air conditioning plant thereon) was prohibitively expensive.

Figure 16 Front elevation 490 Spencer Street, Melbourne

The 'virtual' double glazing comprises the installation of rooms for short meetings on the western elevation with glazed partitions to allow light to penetrate into the office spaces. This side of the building was subjected to solar gain which was cooled by the air conditioning. The virtual double glazing means the short term meeting rooms collect the heat otherwise distributed into other office areas and reduces the air-conditioning load. This was a low cost solution. New external blinds on the western elevation further reduce the internal heat load. The HVAC requires replacement because the energy load has been reduced a smaller system will suffice, however there are insufficient funds to include this measure in the current retrofit. The retrofit reduced energy loads through provision of energy efficient lighting and appliances, PV cells on the roof - a 10kW PV array, which provides 20% of the original building power needs and up to 100% of the retrofitted building power needs, energy efficient desktop computers with low energy hard drives and using laptops, that consume a quarter of the power, in preference to PCs remanufactured, low power Fuji Xerox printers, second-hand fridges and high efficiency dishwashers, lights out stickers, lighting timers, zoned lighting in the open plan office, motion sensors, T5 fluorescent lights in office spaces, LED in foyer and conference rooms, large windows to maximise natural light, some new double glazed windows, a skylight was added to upstairs office to allow natural light and 100% Green Energy.

Water economy measures include WCs with a 6 litre flush and cisterns are filled from washbasins. Only cold water is fitted to the kitchen and bathroom sinks to avoid energy wastage by heating hand water.

Waste was reduced by purchasing second-hand office furniture and carpet where possible, and reusing materials from pre-existing offices, other furniture was made from existing components, and finally paper used is Australian and 80% recycled. In the retrofit ‘redundant’ materials were left in the laneway behind the building – all were taken and there is a scope for a city wide scheme.

Wider efforts were made to change behaviours through the provision of bike racks and showers for occupants. Indoor plants were provided to enhance indoor air quality and serve as natural visual and sound barriers.

4.6.1 Objectives

- The overall objective was to create a zero greenhouse gas emission building.

Energy efficiency objectives can be compromised by other concerns such as occupant behaviour. In this retrofit project, the owners wanted to avoid these compromises, and make energy efficiency the primary focus. The question was: how to achieve energy efficiency within the constraints and limitations of existing buildings?

4.6.2 Retrofit features

- “Virtual double glazing”.
- PV solar supplying 20% to 100% of building power depending on amount of sunlight and energy use.
- Energy efficient lighting.
- 100% Green energy.
- Water efficient appliances.
- Reuse and recycling of building materials.
- Web-enabled Building Management System (BMS).

4.6.3 Challenges

- The key challenge with this building was its inherent poor energy efficiency. Secondly the cost of installing PV was high though it should become more viable as economies of scale are achieved over time.

4.6.4 Outcomes

1. On a sunny day this building is zero carbon.
2. Water consumption is being tracked to compare to similar stock.
3. Financial savings from better managed maintenance are considerable.
4. Higher rents have been achieved post retrofit along with lower running costs.
5. Whilst challenging the benefits are profitable and satisfying according to the owners.

4.7 Case 5 – 500 Collins Street

500 Collins Street illustrates an extensive retrofit to achieve energy and water efficiencies while maintaining high tenancy levels during the works. Completed in the 1970s, 500 Collins Street was renowned for its quality of construction, reflecting modern building standards and services. A consequence of which was that it attracted a high tenancy profile. By 2002, the building had declined to a low B-grade standard through obsolescence and ageing. Despite this decline, the building had retained its tenants. This was due to building size and configuration, an excellent location, good design and sound building management. It was these attributes that led the building's owner to determine that it was suitable for a substantial retrofit. Prior to retrofit, the building comprised a total of 23,500 m^2 of office space, five retail shops and 140 car parking spaces. The project began in mid-2003 and was completed in early 2011. The project was divided into three stages to allow for the almost fully occupied building to operate while the retrofit was undertaken. Stage one was to replace and upgrade plant, and renovate the façade. The second stage was to maximise retail space and reconfigure the car park. Whilst stage three comprised the office floor upgrades.

This was rolled out progressively as leases expired. The work included strip out of each floor and replacing them with new finishes and chilled beam air conditioning. The floor-by-floor upgrade required much planning and could only be realised when tenants vacated space. Generally, this was achieved three floors at a time. It also meant, as much as possible, minimising the impact of the building construction on the tenants. This was achieved by having several lifts dedicated to the builders. Demolition work was completed out of hours and old carpets were laid on the concrete floors to deaden the noise for the tenants.

A chilled beam solution was chosen for the HVAC. The façade was upgraded by replacing glazed spandrel panels with aluminium wall panelling, repairing and refurbishing vertical columns, and repainting. Changes in the floor structure resulted in an increase in net tenantable area to approximately 24,400m^2 with eight additional shops, a small decrease in car spaces, and the addition of secure bicycle racks, change rooms with shower facilities and disabled access and amenities. Foyer entries and public areas were upgraded. Level three was extended onto the podium of level two to create external meeting space and recreational landscaped areas.

The HVAC systems included the installation of new energy efficient chillers with variable speed drives and more water efficient cooling towers and new gas fired boilers for heating replacing oil fired ones. As each floor became vacant, a chilled beam air conditioning system was installed. This is a combined system – with active chilled beams that use fans to diffuse cool air around the building's perimeter where solar loads are high and passive in the interior spaces. The original central ducting was reused in the perimeter zones. The new system reduced the number of fans for all air conditioning, which decreases energy consumption. As the building was occupied, it was necessary to maintain the old system while the new one was installed.

Figure 17 **Front elevation 500 Collins Street, Melbourne**

Energy load was reduced by installing solar panels on the roof for hot water, supplying 25% of domestic hot water, fitting low energy T5 light fittings in all public and tenanted areas, installing variable speed drives on major plant and equipment, and using chilled beam air conditioning.

Water consumption was reduced by installing, waterless urinals, three and six litre dual flush cisterns, flow restricting devices on all fixtures, rain water and condensate capture for landscape irrigation using large tanks in the basement parking area to store water and finally baffles on the cooling tower preventing aerosol spray.

Waste is addressed through on site recycling bins and around 80% of construction waste was recycled.

General environmental improvements included minimising embodied energy of the building, using PVC-free materials where possible, using low volatile organic compound materials, a preference for materials with a high-recycled content, selecting materials for durability and from sustainable sources, encouraging the use of bicycles by providing a secure bike compound for 82 bicycles, plus shower and change room facilities, improving the indoor environment quality by increasing fresh air by 50%, radiant cooling (chilled beams), low VOC materials and reduction in indoor ambient noise levels.

The building controls system was completely renewed. The commissioning of this control system was an ongoing process as each floor was completed. The main electrical switchboard was replaced, and tenancy sub-metering provided to enable effective energy monitoring. The commissioning of plant and equipment is critical in this process so that building management understands how the building functions and is controlled for efficient operation.

4.7.1 Objectives

a) achieve an A-grade building standard.

b) attain a high degree of environmental efficiency, both during the upgrade works and post-upgrade operations (set before NABERS and Green Star ratings were in place).

c) maximise tenant retention during the upgrade to maintain optimum cash flow and provide a potential pool of long-term tenants.

d) elevate tenancy profile by increasing the average size of tenancy, length of tenure and quality of tenant achieve a commercially justifiable return on investment.

4.7.2 Retrofit features

- Energy efficient variable speed drive chillers.
- Gas fired boilers.
- Chilled beams (passive and active).
- Solar panels servicing 25% hot water requirements.
- T5 light fittings.
- Water tanks collecting rainwater and condensate for landscape irrigation.
- Waterless urinals and dual flush cisterns.
- Flow restricting devices on all fixtures.

4.7.3 Challenges

The key challenges with this project were retrofitting with tenants in situ. Furthermore the approach necessitated the continued operation of existing service whilst new installations were being fitted.

4.7.4 Outcomes

1. Energy was modelled to achieve a 30% reduction in air conditioning, 50% reduction in lighting and 15% reduction in hot water usage.
2. Water modelled to achieve 40–50% savings.
3. Sustainability Victoria and the building owner conducted a productivity study in 2007-08. The study found a 39% reduction in average sick days per employee per month 44% reduction in the average cost of sick leave, 9% improvement on average typing speeds and significant accuracy improvement of secretarial staff, 7% increase in billings ratio, despite a decline in average monthly hours worked, 7–20% reduction in headaches, 21-24% reduction in colds and flu, 16–26% reduction in fatigue. It is believed these results are due to improved air quality and building amenity.
4. Reduced maintenance costs are due to reduction in plant and equipment as well as more efficient plant, and better monitoring of plant through the BMS.
5. The rental value of the refurbished space has increased considerably.
6. Over the project, the team maintained ongoing support of tenants with an occupancy rate not falling below 70%. The building now has fewer tenants, meaning the number of larger tenants has increased.
7. The building has gained a 5 Star Green Star Office Design v1 rating.
8. The lessons from this project were the importance of communicating with tenants. Secondly strong project management leadership, so that the team understands the sustainability objectives of the project and works to assess all elements against the ESD criteria. Thirdly, careful management and control of noise and temporary service shut downs. Fourth is engaging an ESD consultant, who advocates for the ESD principles in the project team. Finally engage an independent commissioning agent whose role is to specify commissioning and tuning criteria and timing of the project.

4.8 Case 6 – 406 Collins Street

This project provides a demonstration of how to replace the HVAC in a 1960s mid-size office building whilst maintaining tenancy. 406 Collins Street was a modernist six-storey building, typical of late 1950s 'skyscraper' design – built from a steel and concrete structure, plain (non-ornamented) façade, with a strip of windows on each floor facing Collins Street. The building was extended in 1961, when four storeys were added. The only feature remaining from the original 1897 building is the 'Atlas' statue, which was in the decorative pediment at the top of the building, is now located at the street level by the building entrance. The HVAC system was typical of the 1960s: minimal capital cost but no concern for energy efficiency. A new owner purchased Premium House in 2006 and decided it would need substantial retrofit.

The building has 4000 m^2 NLA, including a retail store on the ground floor, and eight tenants that occupy at least one floor each. The floor plate is rectangular, measuring about 350 m^2 on each floor. The HVAC system had reached its use-by date. Modification of the existing system was not considered to be a viable option to achieve a significant improvement on energy efficiency.

Figure 18 **Front elevation 406 Collins Street, Melbourne**

4.8.1 Objectives

a) improve the energy efficiency of the building,

b) achieve at least a 4.0 star NABERS Energy rating, and

c) reduce the carbon footprint and use green power sources.

4.8.2 Retrofit features

- Variable Refrigerant Volume (VRV) air conditioning system.
- Zoned floors.
- Economy cycle dampers.
- Automated night-flushing.
- Roof sunshade.
- Internal and external shading in courtyard.
- Motion light sensors in stairwells and lifts.
- High efficiency lighting in common areas.
- Sub-metering system.
- Web enabled building management control system (BMCS).

4.8.3 Challenges

The main challenges for the team were dealing with the difficulties typically encountered in old buildings, and the need to maintain the existing services in a fully tenanted building during retrofit.

Another major challenge, according to the owner, is managing cash flow during the project. Initially he tried to fund the project from the ongoing rent, but it did not meet expenses. The Green Building Fund grant provided $500,000 for the whole project, but only 20% or $100,000 up front with the balance on completion. To make up the shortfall, a loan was secured from the Sustainable Melbourne Fund (SMF). To meet the costs, this project could not have proceeded without the building being occupied and so the challenge was to minimise the impact of the works on tenants.

4.8.4 Outcomes

1. Energy performance should be halved or as low as 25 per cent prior to the retrofit.
2. The building has low water use and achieved a 5.0 NABERS Water rating.
3. With the new system there will be perceptible variations in the internal temperature range. Educating tenants to accept slightly warmer ambient temperatures in summer and cooler in winter will allow significant energy savings.
4. With HVAC improvements made and the installation of the BMCS, the engineers and building management is confident that maintenance will be faster and less costly.
5. Although it is highly likely there will be significant energy improvements, the owner is unsure that there will be direct financial returns on investment. The viability of the project hinged on the Green Building Fund grant and without it, he doubts that the project would have been as extensive, and it would have meant an even lower return on investment.

Figure 19 **Front elevation 182 Capel Street, Melbourne**

4.9 Case 7 – 182 Capel Street

A small commercial office building constructed in the mid-1980s, 182 Capel Street is a pre-cast concrete structure supporting a lightweight steel frame that carries the concrete flooring. It has two floors and a basement car park. The building was purchased in 2003 with the intention of sustainable retrofit. The net tenantable space is 1200 m^2 but a new second floor, will bring this to 1600 m^2. The building faces west, which offers excellent exposure to light but heat on the façade was a problem that needed to be addressed during retrofit. It is positioned near park land and combines commercial, retail and residential zoning.

The mechanical systems were at end of their life cycle – originally the building had its own generator and sub-station, but the generator was removed. About 60% of commercial buildings around the fringes of Melbourne would be similar in size and construction to this building.

The project has not followed a set planning path as the owners are familiar with design and building processes and paced the work around their business commitments. However, when they received a grant from the Australian Government's Green Building Fund the project was required to meet specified deadlines. The grant does not cover all the retrofit costs but it does make an important contribution. To qualify for the grant the owner has to retrofit the building to reduce carbon emissions from an initial 1.5 star NABERS Energy rating; the target is 5 star.

One aspect of the retrofit is the operable windows which facilitate natural ventilation through the building. The windows are located on the western and southern facades and are connected to a weather station which informs the mechanical system which activates the air conditioning to turn on or off and open or shut the windows. A cross-ventilation system allows fresh air in during the day and purges during the night. The building was well insulated so no additional insulating work was required.

4.9.1 Objectives

a) The objective is to significantly reduce the building's carbon footprint. The aim is to reduce carbon emissions by at least 50% and attain a 4.5 star NABERS Energy rating.

4.9.2 Retrofit features

- Automated opening windows, connected to economy cycle and control system.
- Automated external blinds.
- Gas-fired VRF gas heat pump air conditioning.
- LED and fluoro lamps connected to intelligent control system.
- Rainwater collected in (Stage II) tanks located in basement for WC flush and irrigation.
- Green wall (vegetated façade).
- Bokashi buckets for waste disposal, green façade nutrient.
- Intelligent component control systems.
- Additional building sealing and insulation.
- Ceiling fans.
- Fit-out and construction with recyclable materials.

4.9.3 Challenges

a) The main challenge was deciding what to do in the first place. Then there were cost constraints. Other ideas that sounded good on paper were critically assessed and rejected because the costs could not be justified and it was not certain whether they would work.

b) Another challenge was managing staff expectations about when the building construction was to be completed. There were times when the building work was invasive. Doing the mechanical work and replacing the windows was complicated – working around the occupants as they occupied the space. Detailed programming was required to achieve this efficiently.

4.9.4 Outcomes

1. A NABERS Energy rating was due to be conducted towards the end of 2011 with a target of 4.5 to 5 star NABERS Energy equating to a 50% reduction in carbon emissions.
2. Greater than 50 per cent reduction saving 900 litres per day.
3. Socially, tenants are happy with the potential for the building and have decided to stay.
4. Mechanical maintenance will be reduced from $3,200 per annum to less than $1,000 per annum.
5. Lighting maintenance will be reduced from $1,200 per annum to $500 per annum. Commercially, the project was driven by the requirement to achieve an 8% yield on investment which has been achieved to date.

The key lessons learned were to start with the building fabric, and see what can be achieved through modifications here. Then work within the constraints of a realistic budget, to make sure there are real returns on investment. Thirdly ensure there is a project champion. A fourth lesson was to organise high level input, contributing ideas before a budget is committed. This means letting the ideas drive the process and allowing the building to be what it should be. Sometimes architects can push a building too hard, when it's just not going to work and money will be wasted. Decisions need to be value managed. Finally work with the inherent attributes of the building. Workshop all the ideas as a team include engineers, architects, building managers and users in an 'ESD workshop.'

Image Neale Cousland / Shutterstock.com

4.10 Case 8 – 115 Batman Street

This project exemplifies a newly constructed building that uses a range of energy efficient techniques and technologies to achieve an excellent NABERS Energy rating. The building at 115 Batman Street was originally a machinery factory built in the 1920s and had been derelict since the late 1980s. The factory was gutted, leaving only the brick wall façade.

The new building was constructed in this space, combining the new and the old. The basement car park and two of the floors sit within the original walls of the factory, and two new floors sit above. The new area above the original brick walls consists of vitrapanel clad with heavily insulated walls and a new pitched, corrugated and heavily insulated roof. The two lower floors utilise the original space in the brick façade for the windows. The free standing building faces north, with very little shade provided by surrounding buildings

Figure 20 **Front elevation 115 Batman Street, Melbourne**

4.10.1 Objectives

a) introduce state of the art engineering services with very low levels of energy consumption,

b) provide a comfortable working environment to enhance productivity, and;

c) achieve 5 Star Green Star and 5.0 star NABERS Energy ratings.

4.10.2 Retrofit features

- Complete re-construction within existing façade.
- Highly insulated building shell.
- Chilled beams in the ground, 1st and 2nd levels.
- VAV Economy cycle on 3rd level.
- High efficiency gas boiler for heating.
- High efficiency luminaries.
- 15,000 litre rain water tank.
- Solar panels for water heating.

4.10.3 Outcomes

1. The chilled beams coped well with the heat-wave in Melbourne in March 2009. They responded well to the changes in ambient conditions and were found superior to the third floor VAV system.
2. The lighting of base building consumes less than 2 watts per m^2 per 100 lux.
3. The building is performing better than 5.0 stars NABERS energy. The NABERS rating benchmark for 5 stars is 101 kilograms/m^2/year, 115 Batman Street performed at 89-91 kilograms/m^2/year.
4. Socially there is very positive feedback from the staff about the work environment.
5. The system is simple and plant is accessible and this makes maintenance straight forward.
6. Total building outgoings are less that \$60/m^2 which compares well with most commercial office buildings in the city and near-city locations where the outgoings are range from \$70 to \$90/m^2.

4.11 Case 9 – 385 Bourke Street

385 Bourke Street is an example of how to manage the retrofit of a very large office building over a long project period to achieve significant energy efficiency improvements. The building is a concrete and steel structure with rectangular windows in a concrete façade. It was completed in 1983, and is 45 storeys high, sitting at a 45 degree angle to the city grid. The building houses many commercial tenants, with retail stores and a large food court on the lower levels. The retail area is 6,000 m^2 and the office, 55,000 m^2.

In 2004, an ABGR rating (the predecessor to NABERS) was conducted on the building and revealed a zero star rating. An environmental performance audit provided a list of options to improve building energy efficiency. Some of the mechanical systems had reached the end of their lifecycle, the recommendations were mainly directed at improvements to the efficiency of the HVAC system.

4.11.1 Objectives

a) lift the building from a zero NABERS Energy rating to a 2.5 rating. This objective was essential for the building to maintain relevance in the marketplace.

4.11.2 Retrofit features

- Upgraded BMCS.
- Variable speed fan drives.
- Economy mode.
- Lux meter sensors.
- T5 lamps.
- Quantum heat pump units.
- Flow restrictors in washrooms.
- Commingled recycling program.
- Metering.

4.11.3 Challenges

Effective communication in the project team between consultants and contractors was sometimes challenging.

Another issue was getting the installed equipment and control strategies working and tuned correctly post commissioning and an external technical agent from was brought in to assist with the tuning of the building performance strategies. Performance-based contracts were not used due to the amount of additional work going on simultaneously. It would have been difficult to separate the contribution individual component projects were having on the whole energy performance unless all work was rolled under the same contract.

Commissioning took over a year as there were issues getting the BMS running effectively. There were some complex control strategies that needed seasonal tuning. Furthermore parts of the installation works had technical issues relating to latent conditions and there were differences in perception of scope.

Another challenge was the site documentation was not up-to-date. This was a problem because it meant not knowing whether the new control strategy would negatively impact the operation of a different component of the complex system.

The project team decided to write the documented programming specification a revised building technical manual. This made clear what changes were required to all elements of the program and assisted in having accurate as-built manuals on these complex strategies.

Maintaining occupancy rates was a challenge. This relates to the NABERS Energy rating as it is calculated on the energy used, square metre occupied and the hours of operation, which means, to gain a significant rating, the building needs to be substantially occupied.

4.11.4 Outcomes

1. 372 MJ/m^2 per annum saving which is a 41% reduction in CO_2; a NABERS energy improvement from 0 to 3.5 stars.
2. NABERS Water star achieved 3.5 stars.
3. The works brought up a number of maintenance issues which are being addressed and management needs time for the maintenance works to stabilise in order to determine the cost impacts and determine a decrease in HVAC comfort complaints.
4. The increase in NABERS Energy rating will certainly open up the building to a larger market of tenants, in particular those that are seeking a NABERS rated building.

Figure 21 **Front elevation 385 Bourke Street, Melbourne**

4.12 Case 10 – 530 Collins Street

530 Collins Street was vacant and was retrofitted to meet contemporary standards, including energy efficiency. The owner, GPT Wholesale Office Fund, reported that 92% of its tenants rated sustainability as 'very important' or 'important' to their business. The development took a broad view of sustainability making social and environmental improvements. For example improvements included coffee shops, informal meeting spaces and increased food options. 530 Collins Street was built in 1989 and has a NLA of 65,775 square metres. The pre-retrofit NABERS energy rating was 4 stars and this was achieved using 25% Green Power. The target is at least 4.5 stars. The NABERS water rating was three stars.

4.12.1 Objectives

The target is to achieve a NABERS Energy rating of at least 4.5 stars. The building sought to reduce its annual greenhouse emissions by 40% compared to the industry average.

Figure 22 **Front elevation 530 Collins Street, Melbourne**

4.13 Comparative analysis of sustainability measures adopted in retrofits

This section of the report presents a summary of all the sustainability measures implemented in the case study retrofits. In all 70 measures were implemented across the 10 cases. These measures can be categorised as environmental and social measures. Many of the environmental measures were implemented because of the potential economic benefits.

Not surprisingly most of the measures, forty three in total or 61%, related to the building services. In all 51 measures, or 73%, were related to energy efficiency and this reflects the importance of energy efficiency in sustainability, in the attainment of NABERS energy ratings and Green Star ratings. It also reflects the poor energy performance of the existing stock.

Water economy measures in comparison featured eight times (11%) in retrofit measures. The reasons could be that water economy is not as important as energy, or more likely, that due to water restrictions imposed during the 10 year drought in the early 2000s, many Melbourne buildings operate efficiently in terms of water. A number of case study summaries noted that existing water economy was good.

Measures to the building fabric featured 12 times (17% of all measures undertaken) and are associated with energy efficiency. Opportunities for building fabric measures occur less frequently, involve access challenges and disruption to occupants, as well as often being expensive. However once undertaken, these measures may be a more long term solution than upgraded services which require maintenance and will be replaced typically within a 20 year lifecycle.

Social sustainability was mentioned in four case studies mostly in respect of amenities provided to users in respect of improved internal environmental quality (IEQ). One project featured a roof top garden which provided a pleasant social space for users, however the rationale for inclusion also included environmental benefits of reducing the heat island effect, insulating the roof and reducing energy use (an economic benefit). Finally one project featured a building which housed small businesses which were driven by social justice and equity issues; thereby having a positive social sustainability contribution. Overall social sustainability has a much lower profile within the retrofits.

Table 18 below summarises the case studies and whether they had financial assistance from the Green Building Fund, adopted out of hours working and their social, economic and environmental features.

Table 18 Case studies summaries

Case study	Assistance of Green Building Fund	Out of hours working	Economic features	Environmental features	Social sustainability
131 Queen St	x	x	x	x	x
636 Bourke St				x	x
247 Flinders Ln				x	x
490 Spencer St			x	x	
500 Collins St		x		x	
406 Collins St	x	x		x	
182 Capel St	x			x	x
115 Batman St			x	x	x
385 Bourke St				x	
530 Collins St				x	

4.14 Comparative analysis of retrofits and building attributes

Having undertaken a qualitative description of the key aspects of each retrofit in the 1200 Buildings Program, this section adopts a more quantitative approach to understand the similarities and differences between the cases. Using criteria which previous studies have found to be important in retrofit, this section analyses a number of retrofit attributes and compares and contrasts their relative importance.

4.14.1 Buildings Owners

Swallow (1997) found that owners were important in retrofit and face different motivations to act. This study confirms that there were different owner types who acted with different priorities. To date, five of the ten projects had owners or tenants who were directly involved in the construction industry with a specific interest in sustainability. Furthermore they state that were using the retrofit as an opportunity to further develop their knowledge and expertise in sustainable retrofit to market to clients post retrofit. In these cases there is a degree of self-interest motivating actions as well as some commitment to sustainability. Of the remaining six, two were committed to environmental and social equity issues through the nature of their work. For these parties, sustainable retrofit offered the opportunity to 'walk the talk' and demonstrate their commitment tangibly. Three owners can be classed as institutional investors, traditionally interested in economic performance of assets within their portfolios. For these parties, the motivation was to maintain and increase the profile and attractiveness of the asset in the marketplace; so the drivers can be said to be economic and environmental and social.

4.14.2 Building age

As buildings age, they become worn and subject to obsolescence (Baum, 1991; Barras and Clark, 1996; Douglas, 2006). Without retrofit, buildings affected by obsolescence attract fewer tenants and lower rental income, eventually becoming unlettable and requiring demolition (Swallow, 1997). Many of the case studies cited the commercial case for retrofit as a driver. Wilkinson (2011) found that the relationship between retrofits and building age was strong and the primary consideration for stakeholders involved in building retrofit is the age of the building and services. Many studies have noted that age is important in retrofit (Barras and Clark, 1996; Ball, 2002; Fianchini, 2007).

When the age of the buildings is examined, 50% of retrofit works occurred to buildings aged between 19 and 41 years of age, indicating that the stock underwent the first major retrofit. It is acknowledged that buildings require some extensive remodelling after their first 20 years and that the fabric and also the space plan ages to a point where reconfiguration and renewal is necessary (Brand, 1994). The mean age of the buildings in the study was 43.9 years; which is older than the mean for the entire commercial stock for Melbourne of 31 years (Jones Lang LaSalle, 2008) and it makes sense that these older buildings are those undergoing retrofit. Ten per cent of retrofit works occurred to buildings aged between up to 18 years and this indicates that the newer stock suits the needs of contemporary users much better than the stock aged 19 years plus. The literature typically refers to the first major retrofit being required at 25 years or so (Brand, 1994; Douglas, 2006). The buildings aged over 42 years in the analysis accounted for 40% of retrofits.

The interpretation is the majority of buildings eventually reach an age in Melbourne's market whereby they no longer meet the demands or expectations of the market even with retrofit. An implication of these findings is that owners and designers should be realistic of a building's lifecycle and avoid over-specification of commercial office buildings whereby extra resources are committed to buildings to provide a hypothetical life of 100 plus years for example. When in reality societal tastes, needs, perceptions and expectations will have changed so much so that the building will be perceived to no longer meet market expectations after this time. In terms of sustainability issues, this means that consideration of building 'de-construction' must be a higher priority for designers, owners, legislators and society. 'De-construction' is the ability to partially or wholly dismantle or 'de-construct' a building or parts thereof, during or at the end of the useful lifecycle, and it allows for the reuse of building components and/or recycling of those materials for further use elsewhere. In essence the building life-cycle of components is extended for use in other buildings or structures. It can be argued that adoption of deconstruction is a move away from the philosophy of retrofit; however the argument is that the concept of retrofit as being within building and within site is extended to embrace across building and across site applications thereby the whole life cycle of materials and components is fully utilised. Retrofit will be more easily accommodated if de-construction has been considered in the initial building design.

Compared to the earlier study (Wilkinson, 2011) where 70.6% of retrofit works occurred to buildings aged between 19 and 41 years of age, this figure is higher than the study looking at 1200 Buildings Program buildings. Where younger stock is concerned the percentage of works is similar; 7.18% of retrofit works occurred to buildings aged between up to 18 years and 10% in the second study. The major difference is in the older stock where 22.76% in the first study were aged over 42 years and in the second study, 40% of works fell in this age category. It is possible that the 1200 Building Program attracts older stock into retrofit, though with such a small sample this is cannot be statistically supported.

4.14.3 Location

Kincaid (2002), Douglas (2006) and Highfield (2000) found location to be important, the highest number of cases, five are located in the low prime areas of the CBD, with one case in the low secondary and four in the fringe areas. Low prime is the second ranked location. This compliments Wilkinson's (2011) earlier study analysing 7393 CBD retrofits from 1998 to 2008 where retrofits were more likely to occur in better locations a total of 51.4%. In that study 26.10% of retrofits were reported in low prime locations and here the percentage is much higher 50%, though the sample here is very small. A difference occurs with the low secondary rate of retrofits – in the earlier study it was the highest ranked location at 27.3% and here is the lowest at 10%. With the fringe activity in the second study the reverse is true, the rate of retrofits is 40% of the total compared to 8.78% and possibly reflects a drive to enhance the stock in the location and possibly the owner and tenant composition of the latter study.

4.14.4 Aesthetics

Six cases were deemed very aesthetically pleasing. Aesthetics was noted as being important in retrofit (Chudley, 1991) and was assessed on the basis of massing, form, composition, use of materials and so on (Zunde, 1989). One was classified as neutral and three cases were classified as 'unattractive'. This compares favourably with Wilkinson's (2011) Melbourne CBD study where 62.67% of stock ranked aesthetically pleasing was retrofitted. At the other end of the scale, in the previous study 16.6% of unattractive buildings were retrofitted and here a higher proportion of 30% is retrofitted. In the majority of cases presented here little work was undertaken to change the buildings appearance externally. Again this is likely to be due to the owner / tenant motivation of the case study group. Overall some findings are consistent with Wilkinson (2011) and Omeheng (1996) in terms of aesthetic qualities of retrofitted stock.

4.14.5 Location of vertical services

Gann and Barlow (1996), Snyder (2005), Szarejko and Trocka-Lesczynska (2007) found that the location of the vertical services was significant in building retrofit. In this study most buildings had services located centrally (four) and also to one side (four) within the building, followed by multiple locations (two). This reflects the scale and age of the buildings in the sample. Compared to Wilkinson's study (2011) most retrofits occurred to stock with services in central locations (56.49%), followed by multiple locations (33.64%). This study shows an increase in the prevalence of stock retrofitted where the vertical services are located to one side of the building. There is some consistency with the highest rate of 40% being to buildings with centrally located stock. Again the sample size is small and results should be read with this in mind.

4.14.6 Existing land use

In this study 50% of retrofits occurred to buildings classified as sole office land use, 30% for office and retail land use, 10% to office, retail and residential and 10% hotel use. This profile is consistent with the Wilkinson study (2011) where 52.84% of all retrofits occurred to buildings classed as 'office' only. When other land uses are examined the profile changes; in the earlier study 44.8% were office and retail land use, which is higher than the current study. Furthermore in the earlier study only 2.37% were attributed to other land uses, whereas here it is 10% to office, retail and residential and then 10% to a hotel land use. This suggests a wider range of land uses are drawn into retrofit with the 1200 Buildings Program than previously.

4.14.7 Floor area

Typical floor area is an attribute related to physical dimensions of buildings or size (Kincaid, 2002; Arge, 2005). Floor sizes were divided into small, medium, large and extra-large categories for analysis. 60% of all works occurred to buildings with a typical floor area of 700 m^2 or less (small), with 20% of all works to buildings with a medium typical floor area of 701-1178 m^2. Large typical floor area retrofits (1179 m^2 plus) accounted for a further 10% of works, with extra-large typical floor areas of over 1346 metres squared accounting for 10% of works. Floor size is an important consideration in retrofit with floors that are able to accommodate user needs and market demands that are most likely to have the capacity to be adapted. Wilkinson (2011) found that it appeared that owners and occupiers retrofitted floors (and buildings) to suit changed needs regardless of size and that the Melbourne market had a more or less equal demand for all groups of floor sizes. In that study the percentages were 23.79% (small), 27.34% (medium), 20.32% (large) and 27.93% (extra-large) of works. The current study has a different profile reflecting smaller scale projects and may be affected by access to funds and the type of work undertaken post 2008.

4.14.8 Street frontage

Street frontage is a measurement of the building's width in metres. Building width is an important criterion in retrofit, for example the Povall and Eley's study in Markus (1979) established a benchmark for building width in retrofits and this was found to be true 26 years later (Arge, 2005). Building width was an important aspect of office retrofit (Ibid.). In the Melbourne stock, buildings can have over 200 metres of street frontage. In this study 20% were less than 10 metres wide, 10% 11-20 metres, 10% 21-30 metres, 20% 31-40 metres and finally 20% were 61-70 metres wide. Overall the stock in the study comprises building widths mostly in the lower range – up to 50 metres wide as in the earlier Wilkinson study (2011). No very wide buildings feature in the current sample.

4.14.9 Historic listing

Historic listing has an important affect on retrofit. Due of the date of settlement of Melbourne and the age of the buildings, it follows that this is an area where a high amount of buildings have heritage overlay or listed status. In this study only 20% of retrofitted buildings had historic listing or heritage overlay. This contrasts to Wilkinson's 2011 study where the converse was found and heritage overlay / listed stock experienced higher rates of retrofit than the non-listed stock. Where overlays exist or listing occurs owners are required to heed requirements and obligations established by legislation in respect of the properties external appearance or materials used and /or also with regards building interiors in some cases. The benefits of retrofitting heritage listed buildings are that the cultural and social values embodied within the building are retained for the wider benefit of the community (Ball, 2002; Snyder, 2005). Some of the case study buildings date from the 1897. Though, subject to numerous retrofits in order to ensure that market needs are met over time, they are highly regarded by tenants and owners and perceived to embody qualities such as a sense of history and quality and convey a sense of prestige and distinction to occupiers. In the 1200 Building Program there is a preference for non-listed buildings.

4.14.10 Number of storeys

When the number of storeys in a building is examined, 70% are to buildings under 20 storeys or low to medium rise stock. Retrofits to high rise buildings (that is 21 to 45 storeys high) occurred 30%. There are some similarities to Wilkinson (2011), where 30.37% of retrofits occurred to high rise stock. Higher rates are noted in the low to medium rise category and this is due to the overall size of buildings which have joined the 1200 Buildings Program.

4.14.11 PCA grade

Property Council of Australia building quality grade can be interpreted as an economic factor. Broadly associated with Property Council of Australia building quality grade is a building's current value, investment value and yield. The economic goal or financial drivers of retrofit and cited by a number of 1200 Buildings Program owners is to increase value post retrofit, after construction and development costs are taken into account. Retrofit has to be economically viable to be successful (Swallow, 1997; Ball, 2002; Highfield, 2000; Kincaid, 2002; Snyder, 2005; Kersting, 2006) and there has to be market demand to bring about economically viable project. Positive user demand was an important criterion in successful building retrofit (Ball, 2002) and with the vacancy rates for offices being historically low during the period covered by this research; there has been positive user demand throughout the CBD. However there is another way of interpreting Property Council of Australia building quality grade and that is a measure of building quality or building amenity levels.

Depending on the condition of a building it is possible to increase the overall quality with retrofit (Boyd and Jankovic, 1993; Isaacs in Baird et al., 1996; Swallow, 1997; Snyder, 2005; Kersting, 2006). Office building quality is measured in various ways but, generally and across all land uses, can be stated to be either provision of a greater number of amenity features, attributes and or a higher standard of services, features, fixtures and fittings. In Australia offices are graded by the Property Council of Australia with Premium as the best quality and highest rental levels, with A, B, C and D grades having progressively less amenity and quality and less capital and rental values (Property Council of Australia, 2007). It is possible to increase the office quality grade from one band to another and simultaneously increase the rental and capital value of the building. Overall the results showed that the ungraded stock was most likely to be worked on (50%), followed by B grade stock (20%). Premium, A and C grade stock represented 10% respectively. It appears that owners are most active in working on ungraded followed by B grade stock. These results contrast to the earlier study where B grade buildings were most likely to be worked on, followed by ungraded stock and A grade stock (21%). From 1998 to 2008 owners were most active in retrofit to A and B grade stock. Premium stock accounted for 10% of work and reflects the age and condition of this type of stock within the CBD. Half of the projects occurred to offices which are not classed under the Property Council of Australia building quality matrix. This stock is low quality; hence it does not achieve the standards required for inclusion in the Property Council of Australia building quality matrix.

4.14.12 Degree of attachment to other buildings

In the context of retrofit, degree of attachment to other buildings refers to ease of access for contractors to all sides of a property. In the CBD many smaller low rise buildings tend to be attached on two sides, with the larger high rise stock more likely to be detached. Povall and Eley in Markus (1979) and Isaacs in Baird (1996) noted that the degree of attachment to other buildings affected not the ease of retrofit and the desirability of retrofit. Buildings which are detached are easier to adapt externally because owners can get access to elevations for construction works such as re-cladding the buildings external envelope for example. Internal retrofits are easier to undertake with detached or less attached properties as owners can gain access for materials delivery and removal of waste without disturbing or needing to engage in negotiations with neighbours. Wilkinson (2011) found this to be true in Melbourne CBD retrofits from 1998 to 2008. Buildings which are detached were equally most likely to undergo retrofit (50% of all 1200 Building Program cases). However buildings attached on three sides accounted for 50% of retrofits which is a marked change to Wilkinson's 1998 to 2008 study where only 8% occurred. The negative impact of access issues faced by owners in retrofitting buildings with a high level of attachment to adjoining properties was not found in this study.

4.14.13 Site access

Site access to the building is important in building retrofit (Povall and Eley, 1979; Gann and Barlow, 1996; Snyder, 2005; Kersting, 2007; Remøy and van der Voordt, 2005). The reason is that contractors need to set up site accommodation and deliver materials and equipment to the building during retrofit works. The ease with which this can be accomplished affects cost and the duration of the retrofit project. Furthermore site access to and from a building determines whether owners can undertake retrofit with occupants in situ.

In this study buildings with least good levels of site access (street only) are most likely to be adapted (50%), followed by buildings with street, side and rear access (30%), and lastly buildings with access on all sides (20%). Collectively half have good to very good access thereby supporting the assertions of previous studies in respect of accessibility (Povall and Eley in Markus, 1979; Isaacs in Baird et al., 1996; Wilkinson, 2011). Buildings with site access from the street only had a lot of work undertaken and the issues regarding access for contractors were overcome in some cases by working outside normal working hours at night and weekends. This added to time and costs in the retrofits.

4.14.14 Conclusions

This part of the research project had two aims;

1. **To gain a deeper understanding of the improvements made to existing office buildings in the 1200 Buildings Program in Melbourne, Australia.**

   The analysis of the case studies has provided an in depth qualitative discussion and analysis of the ten case studies. In summary of the sustainability measures undertaken;

   - 61%, related to the building services.
   - 73% were related to energy efficiency.
   - 11% were water economy measures.
   - 17% of all measures were to the building fabric.
   - 6% of measures had a social sustainability component.

The second aim was;

2. **To undertake a comparison of current practice to identify similarities and differences in approach to retrofit in the 1200 Buildings Program.**

   Compared to an earlier analysis of CBD retrofit activity the case study buildings the findings are as follows;

   1. Building owners are motivated by different drivers, and the predominant initiating party in the 1200 Building Program has been built environment consultants who are seeking to develop knowledge and experience in sustainable retrofit whilst upgrading their offices.
   2. Fringe locations feature much more prominently in the cases compared to general trends and earlier studies however low prime is where most retrofits occur and this compliments earlier study and general practices.
   3. Aesthetics is important with 60% ranked as attractive.
   4. Buildings having a wider range of location of services are being retrofitted within the program.
   5. A wider range of land uses are drawn into retrofit with the 1200 Buildings Program than previously.
   6. Buildings with smaller floor areas are generally retrofitted within the program.
   7. The stock in the study comprises building widths mostly in the lower range up to 50 metres wide.
   8. In the 1200 Building Program there is a preference for non-listed buildings.
   9. Higher retrofit rates are in the low to medium rise category and this is due to the overall size of buildings which have joined the 1200 Buildings Program.
   10. Ungraded buildings were most likely to be worked on (50%), followed by B grade stock (20%).
   11. Buildings which are detached were equally likely to undergo retrofit (50% of cases) along with buildings attached on three sides (50% of cases).
   12. Half of all retrofits have ‘good’ to ‘very good’ site access.

5.0 Overall conclusions

Clearly the Zero Net Emissions policy document was ambitious and ahead of its time. Some of the original timelines proposed in the 2002 document have not been achieved and the strategy has evolved to accommodate changes in thinking, technology and economic circumstances (City of Melbourne, 2008). The aspects which have not met the proposed deadline have often involved the changes to legislation and reflect the time required to educate and negotiate these far reaching and innovative regulatory proposals. It is acknowledged also that in some respects for example, energy efficiency regulations within the Building Code of Australia that Australia and Victoria lagged behind other developed countries in respect of minimum standards. Due to economic growth and the under estimation of emissions in 2002, the reported emissions from 2002 to 2005-6 increased by 59% from 3.75 million t $CO_{2\text{-}e}$ to 5.97 million t $CO_{2\text{-}e}$ (Ibid.). Such an increase reinforces the challenge of reducing urban emissions.

Part 1

a) establish whether environmental attributes are important in office retrofit, and;

b) determine where this sustainable office retrofit market is trending.

The results clearly point to a change in the importance of environmental attributes in commercial building retrofit in Melbourne CBD, when compared to the earlier Wilkinson study (2011). The first study covered the period 1998 to 2008 and the second analysed retrofits from 2009 to July 2011. Therefore the reasons for this change are likely to be a result of the changes to the Building Code of Australia, whereby energy efficiency was mandated in Part J in 2006. In addition the Mandatory Disclosure legislation of 2010 is also impacting in the second study. From this study the market for sustainable office retrofit is trending upwards, though it is certainly the case that the market has been affected to some degree by the sustained impact of the global financial crisis.

This study shows that the predictions made by the City of Melbourne in 2008 regarding the uptake of the 1200 Buildings Program have fallen short. In 2011 for example it was predicted that approximately 20 or so buildings would take up the program this level of activity has not taken place and is likely to be partially attributed to the effects of the global financial crisis, difficulties in lending and a general cautiousness in the market.

Part two aims were;

- To gain a deeper understanding of the improvements made to existing office buildings in the 1200 Buildings Program in Melbourne, Australia.
- To undertake a comparison of current practice to identify similarities and differences in approach to retrofit in the 1200 Buildings Program.

The overall conclusions from this part of the study are that the focus is currently on energy efficiency measures, and that the majority of these measures are manifested through changes to the building services rather than the building fabric. Substantial improvements have been afforded to buildings within the program in terms of energy efficiency. Fewer improvements are focussed on water and it may be that some buildings are efficient due to the drought which affected Victoria for a 10 year period during the 2000s. Similarities and differences between the case study buildings were discussed and comparisons were then drawn with previous retrofit practice from 1998 to 2008.

6.0 Further research

It is the researcher's intention to run a Principal Component Analysis (PCA) for the alterations and extensions events using a reduced number of variables. Given the author has undertaken four PCAs of retrofit events in two major studies – it is possible to use the attributes identified in those PCAs as important as a starting point for the PCA. With 123 events, the maximum number of starting attributes will be 24. These attributes will be drawn from those which feature in the four PCAs.

This study has demonstrated that changes in the retrofit market are underway and the sustainable retrofit market is maturing and evolving in Melbourne. The initial study provides a benchmark from which changes may be known and potentially explained. It is proposed to replicate this study again in 2014 to determine what further changes, if any, have occurred. Similar studies could be undertaken in Australian and other national cities to understand how the building stock is transitioning towards sustainability over time.

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