Assessment of the Performance of Green Commercial Buildings

A Sustainable Built Environment National Research Centre (SBEnrc) literature review by Curtin University and the Queensland University of Technology

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Introduction to Green Commercial Buildings

Overview

The built environment in major urban centres around the world has continually expanded since the industrial revolution. With world population expected to reach 8.2 billion by 2030[i], the demand for commercial space will continue to rise, along with the associated environmental and social implications. Environmental impacts result from both the construction and operation of buildings, particularly from energy consumption and the associated carbon emissions. The United Nations Environment Programme indicates that buildings are responsible for 40% of global energy use, and one third of total greenhouse gas emissions[ii]. At this time in Australia there are approximately 21 million square metres of commercial office space in cities, spread across 3,980 buildings[iii]. The problem is that this space has not in most cases been designed with consideration of long-term environmental and social impacts. In Australia emissions resulting from energy use in the building sector are responsible for almost a quarter of the nation's greenhouse gas emissions[iv]. The energy consumption in buildings has been identified by the Intergovernmental Panel on Climate Change (IPCC 2007)[v] as an easy abatement target to reduce emissions, with cost effective reductions of almost 30% by 2020.

The growth of commercial space also brings social impacts. As Australians spend the majority of their day at work the quality of the indoor environment in commercial offices spaces is important for health and well-being. Unhealthy spaces can result in sickness and impact productivity of occupants. In turn this low productivity can be very expensive for an organisation, even more costly than energy bills. As more research is conducted into this area it is likely the uptake of 'green building' will increase. Voluntary green building accreditation schemes, such as the US 'LEED' (Leadership in Energy and Environmental Design), the UK 'BREEAM' (Building Research Establishment Environmental Assessment Method) and the Australian 'Green Star' have been developed to assess buildings according to set criteria on their environmental impact. There have been limited studies examining how well these programs are delivering sustainable buildings across both environmental and social factors. This lack of data is a strong barrier to the progression of green building as there is little evidence to show investors actual improvements in environmental efficiencies of building operation and the human performance of occupants. As market demand for green buildings continues to grow, research needs to produce a multi-disciplinary evidence base to justify increased property values and prove the effectiveness of green building in both terms of environmental performance and social benefits for occupants.

There are over 4 million square metres of Green Star certified space around Australia[vi]. The 2011 Green Building Council of Australia (GBCA) annual report titled 'Evolution'[vii] shows Victoria and Queensland to be leading the green building market with the highest number of projects, with New South Wales having fewer projects but the highest expenditure. Western Australia and South Australia are increasing the number of projects, but at a slower rate than the other states. The private sector doubled its investment in Green Star projects from 2009, totalling $12 billion. Three per cent of federal construction funding went towards Green Star in 2010, with state level investment in local Green Star projects at $664 million. In order to target the government sector GBCA have developed a 'Guide to Green Building' for government members, and have also introduced a PILOT Public Building rating tool.

As Australia's building industry continues to grow (construction has tripled since 1974[viii]), it is vital that efforts are put into targeting inefficiencies through more ecologically sustainable commercial buildings. Figure 1 below shows projections of C0^2 emissions from buildings until 2050 if continuing at business as usual compared to using energy efficient measures[ix]. Obtaining a Green Star rating through the Green Building Council of Australia is one option for targeting these inefficiencies in order to meet Australia's renewable targets.

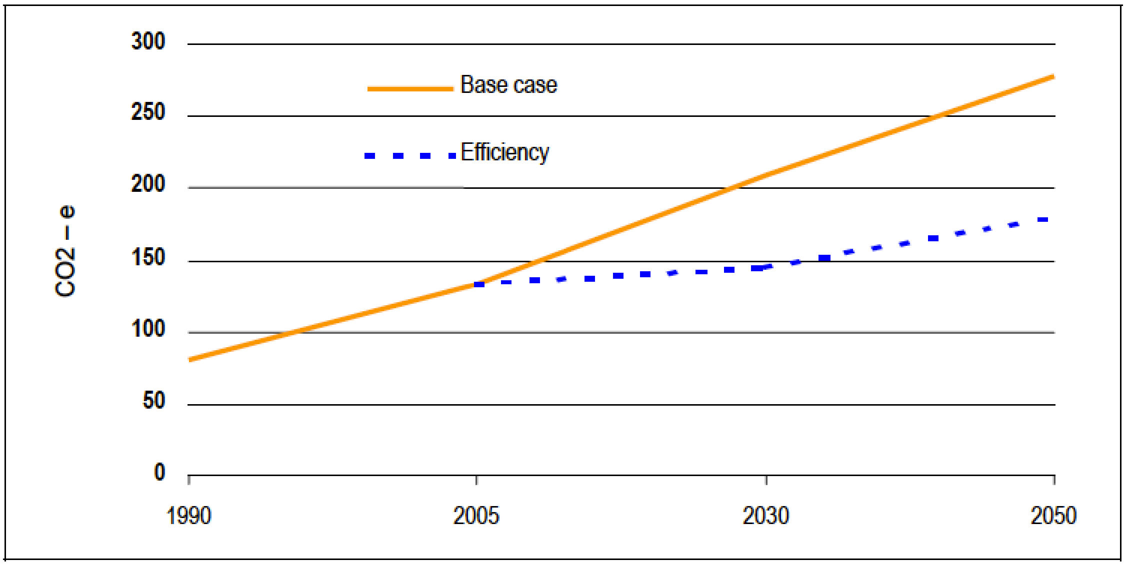

Figure 1 - Projection of $C0_2$ from the building sector in Australia (CIE 2007)

Obtaining a Green Star certification is costly and private and public interests vary as drivers for the uptake of green building in Australia. Whilst private developers prioritise the financial returns, government departments responsible for asset and property management use Green Star as a guide for building, and may not necessarily obtain a rating. Research into the actual sustainability of green buildings will be valuable to both parties, whether it proves the financial value of a Green Star, or justifies the guidelines as best practice standards. For the building industry to progress to more low carbon buildings it is also important to understand the sources of energy consumption in these buildings in order to identify efficiencies. Figure 2 shows where energy is usually consumed, with projections of this energy use through to 2050[x]. Understanding this usage will allow for further improvements in green building design elements and performance.

Inefficiencies are being recognised and building programs launched to assist the updates to buildings. Sydney has introduced a long term plan for decarbonising the city, and as a part of this has just announced a $6.9 million dollar investment into upgrading existing buildings as well as the Better Buildings Partnership now in place. Melbourne has the 1200 Buildings Program which similarly looks at improvements to existing buildings. Whilst these are not necessarily Green Star designs or updates, they are recognition of the need to green the built environment and a significant step in carbon reductions. The Australian Sustainable Built Environment Council have also recognised the need for work in this area and are working on several projects to engage and educate building owners and operators around Australia[xi].

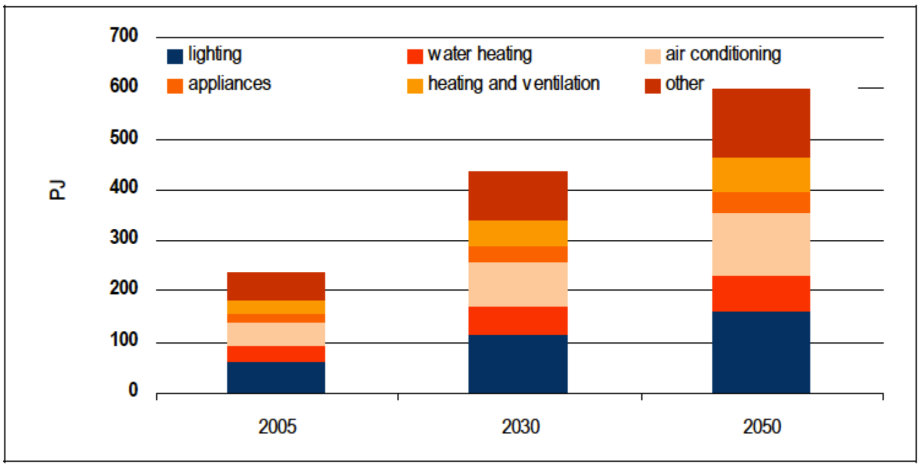

Figure 2: Sources of energy consumption in buildings in Australia (CIE 2007)

As the demand for greener buildings continues, and in order for the industry to effectively grow, it is necessary to demonstrate quantitative data on energy, water and, importantly, staff productivity and occupant satisfaction as part of building sustainability ratings.

Existing Research into Green Building Performance

The following section reviews research studies and reports that have been conducted into green building both in Australia and internationally. Since BREEAM and LEED were introduced there have been many studies on the energy efficiency of buildings and the development of tools and databases. There is exhaustive study into the health, well-being and productivity of building occupants. These studies began appearing in the 1990s, assessing commercial buildings and the causes of illnesses such as ‘Sick Building Syndrome’ (SBS), but over the past 5 to 10 years have become more focused specifically on green buildings. However there are few statistically supported multi-disciplinary studies linking the triple bottom line benefits of green building. This is essential, as improvements in one area, such as achieving tighter, more energy efficient buildings, may impact other areas, such as indoor air quality. In turn, the financial gain through energy efficiency and higher property value may be far outweighed by low productivity due to higher absenteeism rates of staff due to illness.

Studies conducted into commercial buildings (both green and traditional) mainly cover the following topics:

Social performance

- Health and well-being
- Workplace satisfaction
- Office plan/layout
- Thermal comfort
- Lighting
- Indoor Air quality
- Acoustics

Environmental Performance

- Energy use
- Carbon emissions
- Water and waste (limited number of studies)

Economic Performance

- Productivity
- Running costs
- Rent and re-sale values
- Capital outlay for ESD
- Long term savings

MABEL and Probe

The following summary comes from research papers published on MABEL (Mobile Architecture and Built Environment Laboratory)[xii] and Probe (Productivity Occupancy in the Built Environment).[xiii] MABEL is an independent tool developed by Deakin University to assess a building's performance, and does not operate under existing rating schemes such as Green Star, LEED or NABERS. It was designed to provide on-site measurement of key environmental aspects (light, energy, sound and comfort) looking at users, operational energy consumption and equipment scheduling. The MABEL tool was website based and the system crashed, losing all the input data. However developers are still interested in implementing MABEL across the country.[xiv]

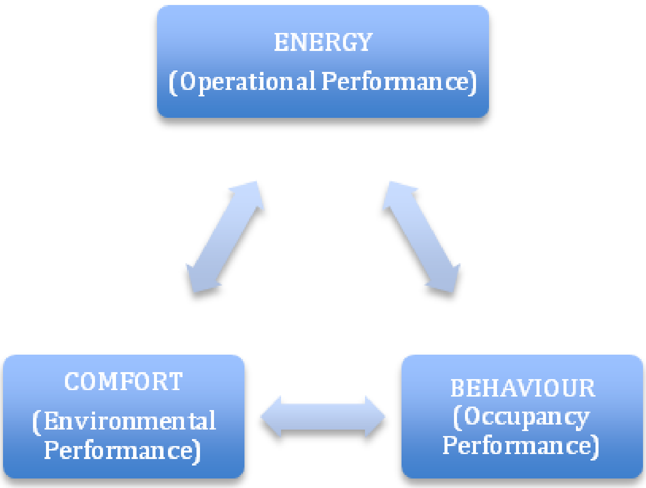

Figure 3: MABEL measurements

MABEL has the ability to ascertain if green buildings are actually performing as rated, whether designers are in compliance, and if a feedback loop exists on project success or failures[xv]. Developers have created a comprehensive set of criteria for measurement, listed below, which can be used in future studies.

Table 1: Criteria used by MABEL to assess buildings

Parameter	Description & Deliverables
POWER	
Energy Use	Excessive energy use, period of operation, AGBR *(now NABERS)* compliance. Energy monitoring.
System Defects: equipment efficiency	Diagnostic fault finding in HVAC control systems, equipment scheduling, and operational periods.
Flow Rates in pipes and ducts	Measurement of flow rates & temperature (energy) in chilled / hot water HVAC systems.
Building Envelope Analysis	Measurement of façade heat transfer and thermal imaging for diagnostic & visual analysis.
LIGHTING	
Background Illuminance	Natural and artificial light levels at the workplace.
Task lighting Illuminance	Workstation light levels from observer to screen and screen to observer:

	total of six lux measurement points.
Correlated Colour Temperature (CCT)	Investigation of light sources and ranges of colour. Light colour variation can have a psychological influence on comfort.
Work place brightness/contrast	Quantification of glare problem in accordance with international best practice regarding glare and discomfort.
Daylight Autonomy	Daylight factors or ratios, which indicate how much electrical lighting is needed to supplement the natural lighting.
COMFORT	
Weather, Solar and Light (external on site data)	The external conditions that influence the internal measured parameters.
Thermal Comfort levels	Use of a “Comfort Cart” to measure (PMV/PPD) occupant comfort at the workplace.
Surface temperatures & Radiant Asymmetry	Influence of Mean Radiant Temperature balance within a work space.
Drafts in air distribution	Draft index at a specific cross-section within a space. Air distribution performance index (ADPI).
Air Temperature Stratification	Variation of air temperature with height within the space.
VENTILATION & INDOOR AIR QUALITY	
Air Change Rates	Room ventilation rates (effective air change): HVAC normal operation & HVAC off: air infiltration.
Uniformity of supply air distribution	Measurement of tracer concentration at a number of locations to determine the balance of the air supply.
Indoor Air Quality (CO^2-e, VOCs, dust particulates)	Diagnostic testing of air quality levels over time and location within an environment.
Fume Hood Testing	The efficiency of capture of contaminants from laboratories.
Air leakage and Building Envelope analysis	Fan pressurisation testing is used to quantify building envelope leakage.
SOUND	
Background Noise: Interior	Background Noise levels at each workplace—frequency dependent. Percentages of loudness over time.
Background Noise: Ingress	Speech privacy vs. speech intelligibility.
Reverberation time	Acoustic ‘liveliness’ (sustained sound) in a room.
Partition sound transmission	Sound transmission class (Rw) through partitions.
Sound intensity; noise sources	Identification of sound leakage areas and sound sources.

In order to give a true evaluation of total building performance, MABEL was used in conjunction with the Australian organisation KODO’s ‘Probe’ tool. Probe was developed by Dr Brian Purdey, now an Associate Professor at Bond University’s Mirvac School of Sustainable Development. The KODO Probe method *‘systematically evaluates workplace performance against the built environment factors known to directly impact occupant health, comfort, satisfaction and productivity. These factors are sorted into 15 key result areas covering the base building, tenancy, workspace design and facility management.*[xvi]’ The MABEL/KODO Probe joint project combines the occupant satisfaction with the technical components of building performance. According to Purdey, the tool produces ‘*topographic maps which colour map the zones of good and bad performance against any chosen variable (i.e. noise, productivity) across the floorplate,* *identify the trouble spots and then use this information to focus building technical evaluations. This then enables one to isolate building related performance issues from those warranting softer solutions within the organisation.'*[xvii] MABEL can calculate a score from the inputs, shown in the map below. Something similar to this score is what is needed in the green building industry to prove environmental and occupancy satisfaction outcomes in the operational stage of a building. The combined MABEL and KODO Probe tools have been used by Australian government departments to assess workplace performance. Although MABEL is no longer in use, Probe still operates independently and has a wide client base. This model could be further expanded through assessment of individual design characteristics in buildings and their contribution to the total performance.

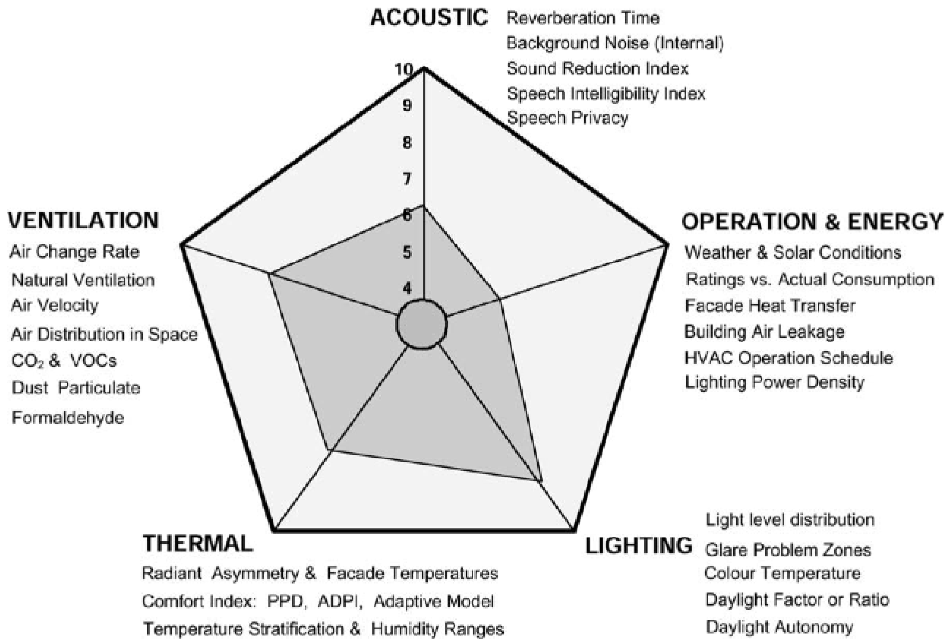

Figure 4: MABEL outcome

Building Productivity Studies

One of the most significant Australian studies to date into productivity in green buildings was recently conducted by Bond University and the GBCA.[xviii,xix] This research examined how occupiers of green buildings perceive and evaluate the role of green workplace environments. Data was derived across 31 different buildings that have been occupied for over 12 months, from three sample groups: building owners, tenants and employees. This data was collected through tailored online surveys, phone interviews and face-to-face interviews. Findings suggest that green workplaces offer greater psychological benefits than physical improvements (health and productivity gains). Occupants had high levels of satisfaction (particularly management), while the main weaknesses were in lack of privacy and noise levels. Below are the findings summarised from a report by Kato and Murugon (2010):

<u>Environmental factors</u>

1. Green Star certified buildings are almost double as energy efficient compared to the average office building.

2. Sixty-six per cent of Green Star certified buildings are performing better or on target for their expected energy efficiency after 12 months of operation.
3. Green Star certified buildings are significantly more water efficient than average Australian offices.
4. The commissioning process was very important to owners in order to achieve ultimate building performance.
5. The private car is still the most frequently used mode of transport among respondents.
6. Many owners and tenants undertake a number of sustainability measures and activities above and beyond what is required by the Green Star rating system.

<u>Business factors</u>

1. It cost more to build green (average 10% addition) but it does not have to; 12 % of the buildings had zero additional cost.
2. Green features cost more for smaller sized buildings than larger sized buildings.
3. There was no correlation between cost of 'Green' and 'date of construction'
4. 'Build big with 5 Star rating' is the way to minimise the cost.
5. Green Star certified buildings have the advantages of securing tenants or selling the building more quickly, rather than adding rent premium.
6. Green Star certified buildings and offices have positive internal branding impacts.

<u>Human factors</u>

1. All three parties (owners, tenants and staff) show high satisfaction levels with their Green Star certified buildings, with tenants being the most satisfied group.
2. 'Instability of air temperature' is the most common complaint (by staff).
3. 'Abundance of natural light' is the most complimented item (by staff).
4. Data from staff indicate that self-assessed health and productivity are not significantly improved in Green Star certified buildings and offices.
5. There is a gap between managers and staff how a Green Star certified office affects environmentally friendly behaviours within the office.

Other Australian research

The Australian organisation 'CETEC-FORAY' have recently announced a large scale study into buildings in Australia and internationally addressing indoor environment quality and productivity. They will be looking at 100 buildings around the world, ten of which will be Australian.[xx] Another significant Australian study researching sustainability in commercial and residential buildings was conducted by Sandy Bond and Peter Newman in 2009. Online surveys were distributed to property practitioners across Australia with the aim of identifying current practices in Ecologically Sustainable Design (ESD) and examining user behaviour. Interviews were conducted to identify best practice examples, and a business case built through identifying property sales and values. The study provides a solid framework for collecting evidence on specific design elements. For example, it found chilled beams and reduction of heat at the façade to be positive features, whereas other design elements did no successfully contribute to higher efficiencies in the buildings.

Leaman, Thomas et al (2007)[xxi] conducted a study titled 'What Australian Building Users are Saying'. Authors compared occupant comfort between 23 conventional and 22 'green design intended' buildings between 2003-2006. The majority of the green buildings were 'first generation', built between 1998-2002. The study found that green buildings generally outperform conventional buildings, but this can vary. Below are the key findings in the green buildings:

- Thermal comfort conditions in summer are generally poor, with some notable exceptions.
- Winter conditions can often be too cold.
- Ratings for design, image, health and needs are usually better.
- Perceived productivity scores are marginally lower on average, but a number of successful green buildings surpass conventional ones.
- Occupants seem to be more tolerant.
- Ratings for lighting are good.
- Internal noise is often worse.

The authors comment that the first generation buildings appear to perform worse than more recent buildings, which may be due to not having the benefit of learning from preceding buildings. Findings identified acoustics and thermal comfort as issues causing dissatisfaction in occupants, and both of these factors have come up in other studies referenced throughout this document. This study did not use benchmarking of environmental performance of buildings (such as energy and water consumption), which makes it difficult to link occupant comfort and satisfaction to specific design elements. The surveys were also perception based which can limit results. A number of individual case studies have been conducted on green buildings in Australia. For example, Peter St Clair conducted a study of Council House 2 in Melbourne and The Bond in Sydney, finding increases in staff perceived productivity[xxii]. There are also studies listed on the GBCA website for certified buildings. However these are often building owner/occupier commissioned studies and, although they may reflect improvements in the building, it is necessary for comprehensive research to be done on a much larger and unbiased scale.

Balancing Multiple Performances of Green Buildings

Voluntary environmental green building rating systems grew following the introduction of the Kyoto Protocol, as countries attempt to reduce greenhouse gas emissions. This growth has increased as more research shows that the commercial building sector has some of the most targetable reductions of greenhouse gas emissions, which mainly comes from greater energy efficiency measures. In addition to voluntary systems, as governments aim to meet Kyoto targets, mandatory energy efficiency schemes are being introduced, such as the Australian Commercial Building Disclosure (CBD) scheme, requiring buildings over 2,000 square metres to report and publicly disclose their energy consumption. As mandatory schemes, such as CBD, are introduced the energy performance of buildings is being measured, and it is questionable whether a green rated building is actually delivering a higher performing building. The rating systems assess the design plans of a building and up until recently there have been no requirements for these rated buildings to provide ongoing energy, water or waste data. It is essential to look at a building's performance past this design stage and assess it in operation.

The social performance of a green building is also often assumed with claims of improved productivity, health and well-being for occupants. These improvements are highly likely but not thoroughly researched or assessed to provide large-scale quantitative evidence. With Australians spending the majority of their day inside offices, the quality of the indoor environment is essential. As building has evolved and new interior and external design elements have changed, the indoor environment has also changed. It is important for the industry to have a solid understanding of positive and negative design elements for a healthy building, including:

Social performance

The social performance of a building includes occupant satisfaction, productivity and well-being. These are influenced by indoor environment factors such as temperature, humidity, air quality, ventilation, acoustics, lighting, ergonomics and greenery. This area is often undervalued but the costs of low productivity and illness in a workplace can be 100 to 200 times the cost of energy bills[xxiii], with just a 1% productivity change in Australia equating to AUD $1.2 billion[xxiv]. Measuring productivity and well-being is difficult. There are a number of other studies which have measured productivity through output, such as data entry staff and have established ideal temperatures and working conditions through controlled experiments. Generally studies found that green buildings seem to perform better than conventional buildings, apart from thermal comfort and acoustics. Design is important, but may not be reflected in current criteria for green building ratings, for example, open plan offices do not offer a satisfactory level of privacy but are favoured in the Green Star rating scheme[xxv].

It is also important that the layout and design allows for natural daylighting, which can impact the health of occupants, and certain lighting levels can maximise productivity and reduce headaches, fatigue and other SBS related symptoms. The materials and interior design can have a major influence over the air quality. This is an area requiring further research as standards appear to be outdated and there is a general lack of knowledge in the market on air toxins inside buildings.

Environmental performance

When benchmarking the performance of a green verses conventional building it is important to match buildings in age, size, purpose and climate zone. Newsham et al[xxvi] challenged a study finding LEED buildings more energy efficient through this process. Green buildings can perform better than conventional buildings, but not necessarily to the level that they should be (according to original design), found in Bordass[xxvii] (2010) and Torcellini et al[xxviii] (2005). These buildings are being rated and going into operation but there is no evidence to prove their effectiveness. A review of water consumption in green buildings was intended but no significant studies were found in this area.

Economic performance

US studies show higher real estate values associated with LEED certified buildings, commanding rental rates 3% higher than similar conventional buildings, and a 16% high selling value[xxix]. Economically, green rated buildings in Australia have no solid evidence of commanding higher real estate values. The 2008 study ‘Doing Good by Doing Green’ by Eichholtz et al has been commissioned for Australia and should provide more certainty for the market as there is currently insufficient evidence that these higher values apply to the Australian industry. Significant value also comes from the productivity improvements for occupants.

Tenant behaviour

Tenant behaviour is a vital component of a building's performance. Europe has shown a strong front with behaviour change programs and highlighted that no two offices or buildings are identical, stressing the importance for flexibility in both training and in the environmental rating tools. A US study by Steinberg et al[xxx] into tenant behaviour showed tenants were aware of recycling processes but not of energy efficient behaviour, it is vital occupants are trained on how to use green building design features for the building to actually perform highly.

From review of internationals studies it does not appear that there is solid quantitative evidence to prove that green building rating systems are consistently delivering sustainable buildings across environmental and social criteria. By all means the programs effectively judge the environmental performance of a building at the design stage, but this is only the intended and not the actual performance of the building. In studies on green building, most attention for environmental performance is given to energy consumption, and not water or waste. Green Star does not currently have any post-construction benchmarking requirements in place as part of their accreditation, however the Performance Tool is under development. Furthermore, designs choices do not seem to be based on any feedback within the industry, making it difficult to decide if design elements are actually affecting the environment. GBCA have case studies available on Green Star rated buildings, which show advanced technology and designs but again, few industry wide studies are available actually assessing the performance of these buildings in relation to conventional buildings.

This lack of benchmarking is an issue for the entire building industry. To be able to construct green buildings it is important to know the average energy consumption of a building by age, size, use and location. The responsibility for consuming the energy in the buildings comes down to every citizen. Even if a building is delivered that can perform at a high energy efficiency, if it is not used appropriately it will perform no better than its conventional counterpart.

Regarding the social performance of a building, studies show that green buildings makes positive contributions to occupant satisfaction. However there is further investigation required, particularly over the long term. Occupiers may be more tolerant to issues in green buildings and excited about the new environment, but over the long-term and through tenant changes this tolerance may drop, showing the need for long-term pre and post occupancy surveying[xxxi]. Without the benchmarking in place to show actual performance of a green building increases property value statistics bring into question the motivation behind green building, being more of a PR and marketing exercise rather than bringing any environmental savings. If a company pays over $100,000 for a Green Star rated building a higher value would be expected, but if the CBD publicly disclosed energy certificate shows high-energy consumption, the true sustainability of a building will be visible.

Drivers and Barriers to Green Building

Market research by Colliers International[xxxii] showed that the main driver for occupying a green building is corporate social responsibility (CSR), followed by cost savings. Cost savings can be achieved without a green rating for a building, shown with the Australian organisation, Investa, who reduced annual emissions from their buildings by 24% and saved $5 million per annum on their energy bill[xxxiii]. Green Star ratings have the advantage of publicly promoting positive CSR for an organisation. The main issue with successful and sustainable green building once again comes back to central barrier of a lack of benchmarking data. Issa and Rankin's[xxxiv] Canadian study of LEED practitioners showed that current literature on performance of LEED buildings is slanted in the rating system's favour, and more reliable benchmarking data is needed to effectively measure a building's performance. Similar results were found in Europe's City Instruments program, where a lack of knowledge on the building inventory was found to be a major barrier for creating well-tailored and cost-efficient programmes.

This lack of benchmarking data may be attributed to negative impacts from potentially poor results. If, after significant investments into a green rating are made, a building is found to perform lower than expected it could damage reputations for designers, engineers and the green building councils. A recently filed lawsuit against LEED brings this to attention where a purchaser is suing the US Green Building Council for mis-representation of energy performance in buildings. Quantitative evidence will provide justification for the high up-front capital investment into green star ratings. The strict credit requirements of the environmental ratings are necessary for regulating the process, but potentially narrowing the sustainability of a building. Designers are likely to choose the most cost-effective solutions for the maximum credit points, which may not include the most environmentally beneficial design. It is important to keep in mind the intention behind a green building and give flexibility in the credits.

For the industry to continuously improve there needs to be shared knowledge on design elements. This is difficult in Australia due to privacy and competitive issues with shared information. Europe has introduced a knowledge-sharing platform that overcomes these problems and could be used as a model for Australia. These feedback loops can assist the fragmentation between designers, architects, engineers and other decision makers, who currently operate independently. The success of a building's performance relies heavily on the behaviour of tenants. If a building is delivered with advanced energy efficient technology but no building management training or systems it may not work to its full capability. Split incentives between owners and occupiers make this difficult. This behaviour change can have wider social benefits as occupants may equate new habits and attitudes into everyday life. Australia's industry has an added disadvantage of somewhat weak regulation and government leadership. This is changing, with the CBD scheme and energy efficiency initiatives but has been slow to progress. Limited government funding support and the high cost for a green rated building limits the market to wealthier, private investors. Europe introduced funding to stimulate innovation in this area, and successfully produced multiple building programs and behaviour change programs.

Drivers Behind Building Green

A 2010 Australian and New Zealand study by Colliers International[xxxv] surveyed decisions-makers tenanting commercial buildings. When asked *'What are the factors driving your organisation's decision to occupy a green building'?,* the top first responses were:

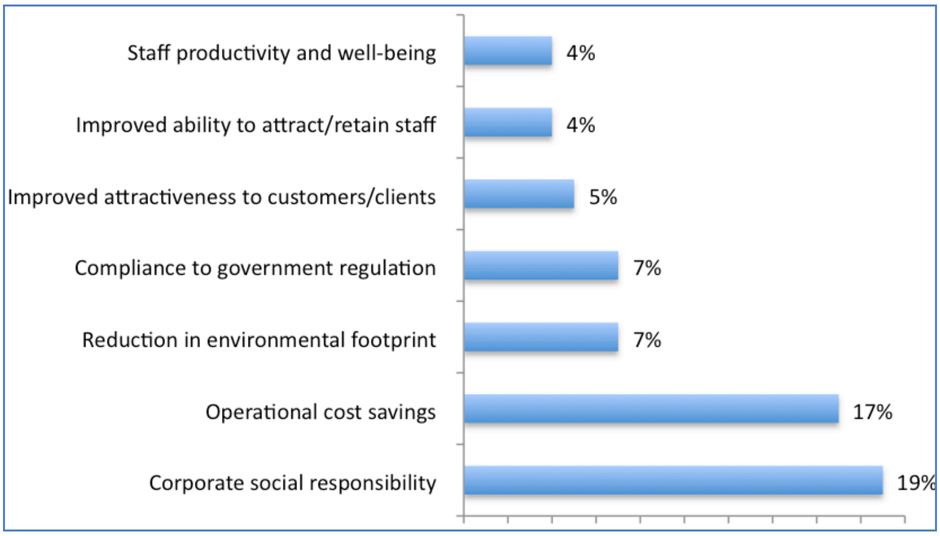

Figure 5: Drivers to occupy a green building

There is growing attention to energy efficiency in buildings and it is becoming a standard for new construction. With regulation now mandating the disclosure of energy consumption it is unlikely building owners would risk producing anything below a four star NABERS rating. It would disadvantage them at a re-sale level and also result in higher operating costs. The mandatory disclosure will be an effective market force, peer pressuring building owners to become more efficient or lose competitive advantage. Government buildings will also drive the industry by setting examples and expectations. As high performing buildings emerge over the next 12 to 24 months, it is likely other building owners will observe and learn from them.

The question remains if operating costs are a main driver, why it is so difficult to measure the effectiveness of a building? Hinge and Winston (2009)[xxxvi] suggest that perhaps energy efficiency and the environment are not the main drivers behind many of the green building accreditations. Organisations may be resistant to publishing the numbers in the case they are lower than expected. As the mandatory disclosure is implemented in Australia it will be an interesting time to observe the performance of Green Star verses NABERS ratings in buildings.

Barriers to Building Green

Lack of research and benchmarks

The first main barrier for green building to progress is the lack of benchmark data that has been addressed throughout this paper. The IPCC state that *'Information about energy efficiency is often incomplete, unavailable, expensive, and difficult to obtain or trust*[xxxvii]. The Australian Prime Minister's Task Group of Energy Efficiency also recognized that 'critical gaps' exist in benchmarking data. Internationally this lack of supporting research can be seen. As part of the LEED study in Canada[xxxviii] LEED accredited professionals were asked to assess their *'awareness, and confidence in research work assessing the cost premiums, long-term cost benefits, and health and productivity benefits of green buildings'*. The majority of respondents were *'uncertain about the size and impact of productivity and health benefits, and about how best to measure them'*.

Some open-ended comments from this Canadian survey mentioned the statistics in current literature are *'typically slanted and selective'* and that *is 'near impossible to discern green* *building costs without designing and pricing a conventional building for the same site and purpose'.* This is reinforced in Newsham et al's study[xxxix] which re-analysed results from another US study finding LEED buildings to be more energy efficient than conventional buildings[xl]. The authors found that the original data was too generalised, comparing overall results from the national building stock to LEED buildings gave biased findings. Another example can be seen in the US study of LEED which examined the energy related environmental impacts of LEED certified buildings[xli], the study used computer simulations but authors commented that *'to quantify the environmental impacts from energy use in buildings it would have been best to take actual measurements from many buildings in many regions of the country….instead probabilistic models were created to simulate the energy related environmental impacts of LEED buildings…'.*

The authors of the Canadian study also presented that LEED practitioners are uncertain about how to measure, document and quantify the benefits and would like to see more focus on energy, water and indoor qualities. The authors concluded what has also been criticized in Australia's green building industry, a lack of empirical data from real-life performing buildings. Wilson & Tagaza (2006)[xlii] discuss that the perceived barriers to green building in Australia could be quickly overcome if it could be demonstrated that buildings provided improvement to indoor air quality and productivity to staff. The lack of data is also seen across Europe. Findings from the 'City Instruments' program suggested energy monitoring and benchmarking for public buildings was needed. The findings state '*Although high CO_2-e reduction potentials in the European building sector are reported, in practice they are only partly realised. The lack of information about what is actually going on in the building inventory is a big obstacle for creating well-tailored and cost- efficient programmes to improve the energy savings of public buildings. The suggestion is to develop a benchmarking tool that does allow comparing the situation of cities on national and European level[xliii].* The plan suggested using tools such as 'Datamine' which is a data collection tool supported by the EU 'Intelligent Energy' initiative. Datamine has now been used across 12 member states and has a database of 19,000 offices. Individual reports are available on the Datamine website[xliv].

A reason for this lack of building assessment may be due to the risk involved. A report by the Green Building Finance Consortium (BCFC) interviewed sustainable property service providers, investors and developers. In questioning their experience with failure and underperformance of sustainable property practice some of the feedback received was the integrated design process was not correctly implemented and energy use was greater than forecast[xlv]. The report suggests if there is a significant underperformance of expected energy savings in a building post-construction, there could be a negative impact on net operating income, expected building value and return on investment. In turn this could create uncertainty in the market and discount investment due to unreliable outcomes.

This is already visible in the US market with a $100 million lawsuit filed against LEED alleging misrepresentation of energy performance in buildings[xlvi]. The BCFC research shows this could be due to faults with the energy modelling, and variations from assumed building management post-occupancy, amongst other issues. One of the primary questions they believe need to be addressed is '*What benchmark data is available from comparable conventionally designed properties?'.* This is a 2010 report, and demonstrates that there is still very little assessment of Green Buildings post construction, leading to a potentially unregulated and flawed industry.

Benchmarking needs to address specific elements, not just energy consumption overall. Perhaps a developer is spending thousands on installing a certain type of HVAC system to receive an accreditation point for Green Star, but how do they know this will deliver the best result? Where can they look to see if this particular HVAC system has had past failures? The IPCC established a number of energy efficiency technologies for use in buildings and the status of these worldwide. It found that substantial reductions in energy can be achieved using existing technology[xlvii]. This type of research could be well utilised on an international basis.

Lack of feedback loops for continuous improvement

One contributing factor to lack of research outlined in the previous section most likely comes from a disconnect between designers, engineers, architects, developers and tenants, each with different priorities. For example, Engineers are responsible for installing the HVAC systems, which must perform well or perpetually result in a bad reputation, something which architects, estate agents and developers don't need to consider as highly. Early design might be for the highest possible cooling capacity which may not be adjusted in a later design stage due to time and budget restriction on engineers, resulting in installation of an oversized HVAC system utilizing more energy than necessary[xlviii].

The European directive is working to fill this feedback gap with 'BUILD UP', a knowledge transfer network for the green building industry. BUILD UP aims to *'to reduce the energy consumption of buildings across Europe by transferring best practices to the market and fostering their uptake*[xlix]*.* In comparison to Australia, feedback mainly comes from specific sectors, such as Engineers Australia, rather than a holistic design approach, which is potentially due to resistance to disclose information and no clear channels for sourcing specific (albeit few) policies on energy use.

An initiative has been introduced in the UK called 'Soft Landings', a concept by the Building Services and Research Information Association (BSRIA). Soft Landings has recognized this break down of communication in the building process and established a framework aimed at assisting the project team when designing sustainable buildings, maintaining strong communication and team work from inception to post-build.

The documentation works through 5 stages to assist project teams[l]:

- Stage 1: Inception and briefing
- Stage 2: Design development and review
- Stage 3: Pre-handover
- Stage 4: Initial aftercare
- Stage 5: Years 1 - 3 extended after care and POE

Behaviour change

Australians are accustomed to resource wealthy lifestyles, especially in comparison to developing countries. Some climatic zones do not necessarily need air-conditioning but it is a use culture that has formed a part of everyday life and is expected. This means that even if a building has the technology, if occupants are not supporting the technology it will not work to its full capability. This will be reflected in base verses tenant loads. Within the behaviour change and feedback process there needs to be education for tenants on how to best use the design elements. 9% of tenants in the Colliers International[li] survey were not even aware they were in a Green Star rated building. This also shows a lack of training and leads to the question of how efficiently can these buildings be operated if the tenants are not even aware of the rating? This requires integrated communication and shared responsibilities across the building process. Staff who change attitudes while at work and see the potential of green buildings may carry these initiatives forward in their homes, and children can be influential on parents with greener schools. Large organisations that go beyond the marketing appeal of green buildings to the actual environmental proof of outcomes have the potential to lead the market and set benchmarks for the construction industry.

Managing up-front costs

The high initial cost is a significant barrier to green building, particularly for Green Star ratings, which can seriously inhibit the potential for commercial buildings efficiencies. The actual cost of achieving the credit rating is not economically viable for some companies, in particular the government. LEED are addressing this area and have introduced an online system to reduce the high cost of intermediary consultant, allowing for more people within the organisation to complete the application process in a more streamlined fashion[lii]. GBCA are also developing more cost effective methods. High up-front investment overshadows the long-term vision of a project. Success in Europe has been seen with the funding of projects compared to Australia, where organisations must pay high fees for a Green Star rating. In addition there is insufficient data supporting the impact of specific design elements to justify cost[liii]. High return on investment is demonstrated in many cases, for example Dumas House in Perth is a 40 year old building that implemented an energy management program mainly focused on lighting, and reduced annual energy consumption by 19%. The capital investment was $130,000 paid back in just two years.

Fragmented market and lack of communication

Lack of communication in the industry from fragmentation is also a major contributor. This leads to a lack of feedback loops in which important information is being missed. An example can be seen with the development of a sustainable school in Attwell, Western Australia. Waterless urinals were installed that did not work, there was nowhere to feed this information and nothing preventing future developers installing inefficient technology, potentially resulting in higher costs[liv]. When the project team rotates and is not present to carry over the design, construction and post-build observation, the distorted feedback loop is limiting the design potential for the buildings[lv].

Whole system consideration

Energy and water efficient measures cannot be considered on an individual basis, but must be considered as a whole system. If the windows are glazed according to BCA regulations, but installed in an uninsulated building, it makes the building no more efficient. This extends to the need for benchmark data and demonstration of what design elements work best together. Perhaps an open plan office will give more natural daylighting but result in poor acoustics impacting productivity. The Green Star ratings also need to allow for flexibility to achieve this holistic result. The credit process is in place to standardize green building, which is important for a fair process. However, all buildings are different which includes the climate they are constructed in, and facilities available. As more research is conducted these stringent controls may show Green Star is not delivering the most environmentally beneficial outcomes.

Incentives

As well as a lack of incentives in the market, split incentives are another major barrier. If the owner is not the occupier of a building, there is discrepancy over who will receive the benefit from higher investment. This is difficult but needs to be a part of the whole system design, which may need behaviour change and testing into what technology is not just energy efficient, but compatible with the user. Mandatory disclosure is assisting this disconnect, although it is a 'stick' instead of 'carrot' approach. The visibility of energy use and productivity increases should hopefully change behaviour and identify inefficient buildings where technology can be updated, or where tenants need guidance.

Subsidies

The International Energy Agency recognise a barrier to energy efficiency comes from high fuel subsidies, which internationally amounted to $554 billion in 2008 (increased from $342 billion in 2007)[lvi]. The agency found these subsidies encourage wasteful consumption and undermine the competitiveness of renewables, and phasing these out could cut global primary energy demand by 5%. As these are phased out the lack of subsidies should actually become a driver of green building through escalated energy prices.

Regulatory

Regulatory barriers are a major impediment to energy efficiency in Australia. There is a lack of consistent, strong and clear leadership and support on federal and state levels[lvii]. Funding is granted and withdrawn when government changes, making the market even more uncertain. Government decisions can often be based on election wins with support of dominant organisations and lobbying groups, rather than long-term planning for Australia. Plans for switching to a low carbon economy must be beyond a three-year election term.

Compared to Europe, Australia's energy efficiency regulation is slow to progress. The government direction and funding has assisted innovation in the European Union, with building efficiency not necessarily reliant on a green building accreditation. For example, a recent article by Chris King[lviii] outlined Germany's progress in sustainable energy use. German regulations requires gas and electricity metres to record how much and when energy is being used, and smart metres to be installed in all new buildings or major renovations. Other regulatory barriers need to be considered. There are limited, well-researched Australian Standards on indoor environment and air quality. This results in a major lapse between rapid growth of new products for buildings and the allowed level of toxins. Other legislation issues can be seen in cases such as the six star Green Star building 'One Bligh Street' in Sydney, where public health laws made recycled water systems difficult to implement[lix].

Future Direction for Research on Green Building

Further research and benchmarking between green and conventional buildings is needed to give an accurate determination about whether, and to what degree, green buildings are delivering truly sustainable outcomes. Tools are already in place that can be used to measure environmental and social factors such as the Deakin University 'MABEL' and KODO 'Probe' tools, which together measure comfort, behaviour and environmental performance to give a holistic rating to buildings. CETEC is an Australian organisation also providing assessment of building performance from environmental and social perspectives. Internationally the University of California's Centre for the Built Environment (CBE), Carnegie Mellon University's School of Architecture and also the US Department of Energy have developed some measurement techniques.

It is important that future research works to a wider scope, and builds on existing findings. There have been many studies performed on indoor environments, it is important to take these findings and apply them to new research and make recommendations for future regulations. For example, ideal temperatures and lighting levels to maximise productivity have been researched, it is now necessary to see if green buildings are providing the correct levels, whilst operating at the intended energy and water efficiencies. Once benchmarks are in place the building industry will have greater certainty and direction for the design of sustainably performing buildings, and there will be more potential for organisations that cannot afford a green star rating to deliver equally efficient buildings. Until further research is conducted there is insufficient evidence that green buildings are delivering a triple bottom line result.

It is important to recognise the significant contribution green building councils are making around the world to more sustainable built environments. However, it is important that these programs do not become PR driven business opportunities, but also focus on delivering truly sustainable buildings. The Australian Green Star rating promotes innovative technology, but inflexible credit points potentially limit the sustainable potential for buildings. For continuous improvement in the industry positive and negative experiences linked to design and operation of green buildings needs to be fed back into a knowledge sharing platform.

Strategic Area 1: Indoor Environment Quality and the impact on health, well-being and productivity

As green building has emerged as a concept a range of factors have been identified as important in creating an environment within commercial buildings that promotes health, well-being and productivity. The indoor environment covers workspace (public and private), air quality and ventilation, dust, acoustics, lighting and thermal comfort. Exposure to the indoor environment can affect the well-being and productivity of occupants as a result of interactions between the structure, building systems, furnishings, outdoor environment and the building occupants and their activities.[lx] Illness and absenteeism from low indoor environment quality can also have a major impact on productivity and performance. Below is a table adapted from the research report 'Productivity and Health in Commercial Office Buildings by Bell et al (2008)[lxi], which shows the basic factors that affect the indoor environment.

Building	Indoor air quality	Acoustics	Lighting
• Exterior design & construction • Location • Accessability • Interior design & layout • Materials • Space & density • Ergonomics • Private/ public space • Level of control • Workstations	• HVAC • Indoor air pollutants • Thermal comfort and ventilation • Air temperature, RH • Air speed and ventilation rates	• Noise in open areas • Noise at workstations • Building and mechanical noise	• LUX • Daylight • Glare

Figure 6: Factors effecting indoor environment

In the past there has been a large focus on improving the energy efficiency of buildings, but not as much emphasis on improving the working environment, whereas the loss in productivity from a poor indoor environment can far outweigh the cost of improving the building. Australia's commercial office space is in high demand, in WA 13% of the total CBD net lettable area (NLA) is from the top four oil and gas companies. Staff are selective in choosing a company to work for and area also seeking a healthy building to work in, and these organisations are constructing green buildings to attract and retain staff[lxii].

Milton et al (2000)[lxiii] quantified productivity losses when they analysed 3720 hourly employees across 40 buildings in the US. Consistent associations were found between increased sick leave, lower levels of outdoor air supply and IEQ complaints. The authors predicted that productivity losses from poor IEQ could be costing the US as much as US$22.8 billion per year. Mendell, Fisk et al (2002)[lxiv] confirmed these findings using economic modelling to forecast the cost of adverse health effects on indoor workers. The study results estimated that improving building environments may result in health benefits for more than 15 million of the 89 million US indoor workers with economic benefits of $5 to $75 billion annually. Safe Work Australia[lxv] report on compensation related claims for injury and illness in the workplace. For the 2005/2006 financial year they predicted that disease alone would equate to a $19.2 billion cost to the Australian workforce, through loss of income, quality of life and productivity. A large proportion of this cost is borne by the community through medical and healthcare schemes. It is important to note that this is based on compensation-related claims and does not include unreported illnesses. In addition, Paevere and Brown (n.d.)[lxvi] showed potential annual savings or gains from reduced illness and increased performance to be worth A$4.2 – 21 billion.

Staff costs are estimated to be approximately 80% of total business costs[lxvii], and the Chartered Institution of Building Services Engineers (CISBE) showed these costs to be 100 to 200 times that of energy bills, thus demonstrating that just a marginal increase in staff productivity[lxviii] can offset operational building costs. Romm and Browning (1998)[lxix] confirmed this with a study showing that a 1% increase in productivity is able to cover the cost of energy bills. Moreover, Milton et al showed that savings from reduced sick leave could more than offset the cost of providing additional ventilation. Seppanen and Fisk (2006)[lxx] conducted a review of studies that reiterated Milton and Milton's findings that the cost of poor IEQ can be higher than costs on energy and ventilation, and that measures to improve IEQ can be cost-effective through savings from improved health and productivity.

Ventilation systems and building design changes are frequent causes of indoor environment problems. Spengler (2000)[lxxi] concluded that, as building systems became more lightweight, they have lost their ability to filter moisture and gaseous compounds, and have a reduced ability to act as a sink area for contaminants. Building interiors are then filled with off-gassing materials and finishes, resulting in a sealed envelope of complex toxins. Spengler also indicated that as building products, finishes and uses have continued to evolve, design guidelines have not addressed the issue of these indoor air pollutants. The Lawrence Berkeley National Laboratory's Indoor Health and Productivity (IHP) project identified that, with regard to the indoor environment's impact on occupants' health and well-being, there is a *critical need to expand the research to a multi-disciplinary level*, and to communicate research that has already been conducted (Kumar and Fisk 2002)[lxxii]. By identifying and communicating the causes of building related illnesses through further research, the design process could deliver higher performing buildings.

Defining indoor environment factors that impact productivity

Indoor air quality

In the 2001 State of Knowledge Report by Environment Australia[lxxiii], the National Health and Medical Research Council (NHMRC) states that considering Australians spend 90% of their time indoors, little research has been conducted into the quality of air in buildings, and according to cited US EPA studies[lxxiv] indoor air pollution is among the top five environmental risks to human health. The report also states that the health impacts from exposure to toxins in buildings are not well understood, and that the physical and psychological responses from the indoor environment are complex. The Clean Air Society of Australia and New Zealand (CASANZ) recognise 21 indoor air pollutants. Below is a table summarising some of the main indoor air pollutants that can be present in commercial buildings, their sources and potential health impacts adapted from the CASANZ 'Indoor Air Quality in Australia: A Strategy for Action'.

Table 2: Indoor air pollutants, impacts and standards

Pollutant	Health impact	Source	Legislation/ standard
Carbon monoxide	Headache, low concentration at low doses Fatal at high doses	Cooking appliances, MV exhaust (i.e. car parks through ventilation), tobacco	NEPM/ NHMRC – 9ppm over 8 hours.
Particulate matter	Respiratory conditions and cardiovascular disease	Wood combustion, cooking, vacuuming	
Lead	Affects central nervous system	Lead based paint or water pipes in older buildings, paint removal processes	Various depending on lead type
Carbon dioxide	Headaches and respiratory illness	Cooking appliances, MV exhaust (i.e. from car parks through ventilation), tobacco	1000ppm (ASHRAE) 5000ppm (WorkSafe for occupational environment)
Formaldehyde	Irritation to skin, eyes and lungs	Woodboard, carpets, linoleum, upholstery, furnishings, finishings, appliances	1.2 mg/m^3 over 8 hours (NPI)
Benzene	Skin and eye irritations, drowsiness, dizziness, headaches, and vomiting	Cleaning products, adhesives	0 .10% weight/weight (Worksafe Australia recommendations)
Total VOCs	Irritation to nose, eyes, airways and skin, nausea, headaches	Paints, adhesives, solvents, aerosols	Made up of several VOCs, NHRMC has goal of 500$\mu g/ m^3$
Moulds and fungi	Hayfever, allergies and asthma	Damps areas, air-conditioning ducts	0 – 500CFU/ m^3 (WHO)

Indoor toxins in commercial buildings typically come from areas such as interior finishings (paints, solvents etc), furniture, office equipment, moisture and HVAC systems. The lack of consistent and legislated guidelines make the design of healthy buildings difficult (Spengler and Chen 2000)[lxxv].As it is already recognised that there is little understanding of air toxins in Australia, it has been raised whether or not green building certification systems give sufficient weighting to the quality of indoor air. A study by John Wargo (2010)[lxxvi] titled "LEED building standards fail to protect human health" indicated how LEED's concentration on energy efficiency has led to a neglect of human health factors in the assessment process for buildings. The author indicates that the use of toxic substances in buildings is largely unregulated and programs such as LEED are placing little emphasis on indoor air quality and the impact from off-gassing of chemicals on the health of the building's occupants. In fact, a building does not actually require any credits for air quality to obtain a LEED rating.

Green Star allocates 5 out of 160 points to reducing health risks from hazardous materials, minimising volatile organic compounds, using products with low formaldehyde emissions. Similarly to LEED, a building does not actually require any of these credits to obtain a rating. CETEC, an Australian organisation, show in research that the allocated Green Star credits do not cover all building products or emphasise chemical emissions testing of paints, coating, adhesives and sealants[lxxvii]. At the same time, it is important to note that GBCA have greatly assisted the development of acceptable, low emission products for building interiors in the absence of general standards and guidelines.

It is important that outdoor air is considered in research, as it is this air ventilation will pull into a building. This will hopefully push the concept of green precincts as the air around the building is also important to maximise the performance of a healthy building. An Australian Government funded project called Clean Air Research Programme (CARP) tested NO_2 levels and dust particle monitors through passive samplers on volunteers at work, home and in transit. The workplace showed the highest NO_2concentrations, with particulate matter highest in the home and transit. This study indicated the indoor environment is also reliant on the outdoor air quality. This is particularly important when green buildings rely heavily on ventilation for accreditation, but if the outdoor air is low quality this ventilation may not make the IEQ anymore beneficial for occupants. Although there has been some work in this area, these reports demonstrate that there is not a solid understanding in Australia of the impacts indoor air pollutants have on the health, well-being and productivity of occupants. The factors are much more complex than assessing energy and water consumption and must be broken down in detail.

Thermal comfort

Thermal comfort, ventilation rates and air quality have been linked to occupant satisfaction and productivity in numerous studies. Fang et al (2004)[lxxviii] conducted studies showing subjects working at lower temperature and humidity rates to be more productive and less susceptible to SBS symptoms. Fisk has also conducted many studies in this area, one which examined worker productivity at various rates of ventilation in a call centre and showed possible performance improvements when ventilation rates were higher[lxxix].

Recommended temperatures for Australian government offices are given as between 20 – 26^{O}C, with no general rule on how much fresh air should be delivered to a room[lxxx]. This follows ISO standards, with differing temperatures for summer and winter. A number of studies have proven the impact of temperature on productivity. Niemela et al (2002)[lxxxi] found that productivity in workers decreased from 5-7% when the air temperature exceeded 25^{O}C. Hedge (2004)[lxxxii] found that raising the temperature in an office for data entry staff from 20 to 25^{O}C reduced errors by 44% and increased data output by 150%, performance decreases when the air is too hot, too cold or it is too noisy (which can come from HVAC systems or background noise). In an earlier study Federspiel et al (2002)[lxxxiii] found the ideal temperature for productivity in an office to fall between 21.5 – 24.75 ^{O}C.

Chappells (2005)[lxxxiv] conducted a UK study examining the building industry's attitude towards thermal comfort and satisfaction in buildings, and how demands are changing as increases in temperature from climate change are occurring. An interesting aspect of this research was the information obtained from the industry. Experts were selected and interviewed across a number of relevant fields. Comments included:

- Clients are so concerned with future climate change that they are making unreasonable requests, for example buildings that can cope with 40 degree heat (in the UK)
- Clients differ in what indirect changes they will make, for example a client wanted a non-air conditioned building, but when they learnt it may require changes to corporate dress standards they declined
- Air-conditioning is socially expected and represents quality and prestige over comfort.
- Generally clients do not want to compromise comfort for environmental sustainability
- Current policy takes comfort standards for granted

The social acceptance of air-conditioned, comfortable buildings was followed in a study by (Wyon 2004)[lxxxv] in which poor indoor air quality was found to decrease productivity of workers and cause dissatisfaction in visitors. Performance drops were shown to be as high as 6-9% in workers. Wyon notes that *minimum ventilation levels have been set well above what is required for the health and well-being of workers*, but employers do not want to give the impression to visitors that they work in a temperature that is not generally socially acceptable. This results in larger than necessary HVAC systems being installed in buildings, requiring larger energy loads and less control over temperature variability.

There has been Australian research conducted in this area, but there seems to be a lack of communication and feedback. A Melbourne study conducted in 1998 by Williams [lxxxvi] explored increasing reports of illness and discomfort in 653 air-conditioned buildings between 1989 and 1996, measuring indoor air quality, ventilation, lighting and air quality, correlated against surveys measuring productivity. Faults in air-conditioning systems were found to be a major factor along with low priority and ignorance to the design, installation, commissioning, leasing and on-going operation of air-conditioning systems. This study is an example of solid data collection that needs to be better communicated to the market.

The personal level of control that people have over temperature is also important. Tsuzuki et al (1999)[lxxxvii] installed individual controls at desktops and showed increases in overall occupant satisfaction for thermal and air quality when occupants had control over the temperature. A similar study by Menzies et al (1997)[lxxxviii] measured environmental factors, comfort perceptions, illness symptoms, and self assessed productivity in a control verses intervention group who were given control over ventilation at their workspace. The intervention group showed a productivity increase of 11% over 16 months, compared to a 4% drop from the control group. Measured against the environmental factors the findings indicated workers were making adjustments according to their preferences which increased productivity.

Ventilation

The recommended ventilation rates according to Australian Standard AS 1668.2 is 10L/sec/person, but as discussed by Bell and Franz (2008)[lxxxix] this number should vary depending on the use of the building, its density and the pollutant levels. There are two issues related to ventilation rates, the first being the impact of occupants' health through toxins in the air and the second the influence this ventilation rate has over productivity.

Wargocki and Wyon (2000)[xc] proved the impact of ventilation on productivity when exposing subjects in an office building to three different ventilation rates from outdoor air supply, with temperature and humidity levels remaining constant. The subjects were unaware of the changes and performed office work throughout the day and were asked at regular intervals to assess the perceived air quality, indoor climate and intensity of their SBS symptoms and thermal comfort. The results showed increased ventilation decreased dissatisfaction with air quality, decreased SBS symptoms and increased performance. For every two-fold increase in the ventilation rate from 3 to 30 L/sec/person productivity increased by an average of 1.7%. The ventilation rates with these positive results are well above minimum standards required. Milton (2000)[xci] found that health benefits continue to accrue when the ventilation is increased over 10L/sec/person.

Bell, Franz et al (2008) indicate that the emphasis on energy efficiency in buildings may be leading to neglect of the need for sufficiently high ventilation rates to avert SBS symptoms. The Australian standard of 10L/sec/person seems too low to offer a productive and healthy workplace based on current research. Wargocki and Wyon (2000) indicate that increasing ventilation rates above minimum levels can increase productivity and in many cases pay for itself through reducing SBS symptoms and increasing air quality. The satisfaction of occupants in relation to temperature has been tested in other studies. Hummelgaard & Juhl[xcii] (2007) conducted a German study that examined indoor air quality and occupant satisfaction between five mechanically and four naturally ventilated open-plan office buildings. The results indicated a somewhat higher degree of satisfaction with the indoor environment and a lower prevalence/intensity of symptoms among the occupants in the naturally ventilated buildings. Paul and Taylor[xciii] conducted an Australian study comparing comfort and satisfaction between two conventional university buildings and a green university building in Albury-Woodonga, Australia. Authors concluded that when occupants perceive their environment as warm it results in a lower level of satisfaction and poor work performance.

A similar study was conducted in the UK by Zhang and Altan[xciv] (2010) which compared occupant comfort in a conventional high-rise office block and a contemporary environmentally-concerned building. The results are different to Paul and Taylor's study, showing that occupants in an environmentally concerned building had higher satisfaction levels than those in the conventional building in terms of thermal and overall indoor environment. The variation in results from Paul and Taylor's and Zhang and Altan's studies show that it is necessary to broaden the sample and compare buildings similar in size, age, occupant density and use. An issue to be addressed in future research is the removal of external variables and a correlation of occupant perception and actual temperature and air movement. Talk-time and typing speed can be used in studies such as Fisk's but more complex measurements need to be used for office buildings, such as revenue per employee. It is important to include actual data collection and measurements of each of these factors. It is important to also conduct measurements of factors including indoor air pollutants, temperature, humidity, radiant temperature, ventilation and air velocity, metabolic rates, and clothing.

Workspace design and ergonomics

A comprehensive review of office design on worker health and performance was conducted in 2005 by the University of Amsterdam[xcv]. It examined how office location, layout and use impacts workers. Out of over 1000 studies starting from 1972, 49 relevant studies were selected. Findings showed open workplaces reduce privacy and job satisfaction and that attention should be paid to acoustic and visual protection. These findings show that creating social spaces and reducing privacy through open plan offices will not necessarily contribute to more productive workplaces. A number of studies by Schwede, Davies & Purdey[xcvi,xcvii] (n.d.) in Australia examined office design and associations to satisfaction and productivity. Authors compared design in new and retrofit office environments, which is important for pre and post occupancy surveys. Satisfaction ratings were analysed from 5000 occupants in 48 office buildings around Australia. The study found that new buildings provide the greatest number of satisfied occupants. Updated environments, which are occupied by the same organisation before and after refurbishment, are more successful than environments that are occupied by a new organisation after an update.

Authors also investigated the relationship between comfort, quality, workspace design and occupant productivity with the aim to identify which design features are characteristics for increasing or detracting from occupant productivity. The study found that design features which generally relate to personal workspace and workspace tools support increased productivity (i.e. furniture usability). Social and behavioural related aspects beyond control (such as privacy and noise) negatively impact productivity. Lee and Guerin (2009)[xcviii] examined indoor environmental quality related to occupant satisfaction and performance in LEED-certified buildings. This study aimed to identify whether the indoor environmental quality design criteria (office layout, office furnishing, thermal comfort, indoor air quality, lighting, acoustics, cleanliness and maintenance) in relation to the overall workspace for LEED-accreditation, could significantly affect occupants' perception of their overall workspace satisfaction and their work performances. This study also found that the consideration of open-plan offices being beneficial for occupant satisfaction and communication, may not always be valid.

Charles, Danforth et al (2004)[xcix] found that freedom from distraction is essential for creating a productive workplace. They report ideal workstation size to be between 5.9 – 13.4m^2, and partitions between 1.4 - 1.6m high depending on employee preference for lighting and acoustics[c]. These studies reiterate the importance of design considerations for occupant productivity and satisfaction. Technical feedback is crucial from these studies for the design to deliver the most productive workplaces. Personal control over space is rated highly, and achieving the highest level of satisfaction may not be aligned with the credits available when applying for a green building accreditation. For example, open plan offices are given credits for a green rated building, but in fact may not be producing the most productive workplaces.

Acoustics

Noise in an office environment can come from insufficient insulation, mechanics (i.e. noisy HVAC or office equipment) or office layout. These can all impact the way sound is transmitted or absorbed, and as outlined by Bell and Franz (2008) this can affect occupant focus, task performance, comfort and stress levels. Standards Australia[ci] give the following guidelines for acoustic levels office buildings.

Table 3: AS/NZS 2107:2000 on Acoustics

	Minimum (dB)	Maximum (dB)
Board and conference rooms	30	40
Corridors and lobbies	45	50
General office areas	40	45
Private offices	35	40
Public spaces	40	50

It seems that green rated buildings sometimes perform poorly in regards to acoustics. A 2002 study by the Centre for the Built Environment (CBE) at the University of California[cii] examined 34,000 survey responses from 215 buildings in the US, Canada and Finland. Results showed that air quality and thermal comfort in green buildings were, on average, rated more highly than traditional buildings. However, lighting and acoustics did not show any significant improvements in comparison. Also using CBE data Jensen, Arens et al (2005)[ciii] found that 50% of occupants in open plan spaces were dissatisfied with acoustics and believe it interferes with their ability to work. This shows the significant impact that acoustics can have on productivity.

In Australia Schwede, Davies and Purdey's studies found that acoustic and visual design features performed poorly across all categories of workplaces. This was also evident in Leaman, Thomas et al's research where indoor acoustics and thermal comfort performed poorly. Another Australian study by James & Zoontjens[civ] (2009) examined integration of Green Star rating tools with the acoustic design of offices and educational institutions. This found that current application of the Green Star rating tools is alone insufficient to achieve internal acoustic qualities appropriate to improving productivity. Other studies have shown that poor acoustics can be a key issue for discontent office staff [cv,cvi], a US study was conducted by Hodgson[cvii] (2008) into an acoustical evaluation of six 'green' office buildings, four of which were LEED certified. The study indicated that LEED accreditation also gives little attention to acoustic design, and found that occupants were dissatisfied with excessive noise and poor speech privacy, and consider that the acoustic environment does not enhance their ability to work.

One of the most interesting points to note from Hogson's study is that when initial meetings were conducted with the designers they were already aware of the problems, but acoustics are not considered a priority in delivering the building. This suggests that 'credit shopping' for environmental ratings is a priority over delivering a sustainable building, sacrificing the social health, well-being and productivity of staff for a green brand. All of these studies show that feedback and continuous improvement to the credits of environmental rating systems are needed to ensure occupants are satisfied. Without this feedback there is little evidence that specific design elements are working. It is essential that materials used in the workplace and design of partitions and spaces consider acoustics as it can have a major impact on the performance and stress levels of occupants.

Lighting

There are a number of areas to be addressed regarding lighting. Bell et al (2008) define three areas as:

1. Daylighting – A combination of sunlight and skylight. This can be controlled through glazing, orientation, interior office plan. A lack of daylight can result in productivity drops
2. Glare – Direct or reflected light (i.e. off computer screen). Lighting systems need to be compatible with the type of work performed. Two types, disability (impaired vision) and discomfort (impacts productivity).
3. Artificial lighting - High frequency electronic ballasts. Insufficient lighting can lead to headaches and visual discomfort.

There have been numerous studies that have linked lighting levels and employee productivity. Abdou (1997)[cviii] showed lighting conditions as a highly cost-effective method of increasing worker productivity in office spaces, and, as cited by Edwards and Torcellini (2002)[cix], Luo (1998) showed that full spectrum lights help increase worker productivity and reduce absenteeism.

Further studies showed that not just improved lighting, but exposure to natural daylight is important. The term 'ill-lighting syndrome' was coined by Begemann (1997) [cx] in a study into artificial lighting in offices, which showed a lack of vitamins from natural daylighting can cause various health problems for workers. Heerwagen et al, 1998 (Edwards and Torcellini 2002) linked daylighting levels with mood and productivity. There has been much research into the levels of healthy lighting for office workers which has influenced building codes with requirements for window thickness, glazing etc. The advantage of increased natural daylighting over artificial lights is that it also reduces energy consumption. Lux levels can be measured as part of assessing the overall indoor environment quality. Australian Standards rate the levels at workstations between 160-320 Lux depending on the tasks performed. Consideration of proximity to windows for natural daylighting, glare, heat gain and sufficient artificial lighting must all be considered in a building design to ensure adequate lighting for maximum productivity and well-being of occupants. Occupant satisfaction with daylighting is often included in self-assessment surveys for comfort and productivity, but it is also necessary to measure lighting levels.

Greenery

The quality of indoor air in a commercial building can be influenced by chemical emissions from flooring, finishings, insulation, fit-out materials, furniture and emissions from office equipment. Removing these chemicals can benefit the health and well-being of occupants. An emerging area of green building design is utilising plants and greenery indoors to lower the presence of these VOCs. A 2009 study by the University of Georgia[cxi] tested 28 different species of indoor plants and found five with the ability to remove VOCs from indoor air. Through improving the air quality, increases to productivity and health of occupants are possible. Authors identified that combining various species in a workplace can target most VOCs, they recommend more research into the VOC removal efficiencies of other plant species.

There is proof that greening the indoor environment can improve the health of occupants. Esther Sternberg's previously mentioned research has shown associations with views over the natural environment to improved health. A Norwegian study[cxii] tested 385 office workers to examine the association between plants and perceived stress, sick leave and productivity. The number of indoor plants had a small but statistically reliable association with sick leave and productivity. Credits are available as part of Green Star for installing indoor plants. However, as pointed out by Ronald Wood in a recent article for 'Fifth Estate' humans and plants require different levels of lighting and it is important to consider this in workplace design. Wood emphasises that current BCA requirements for commercial glazing do not meet plant light requirements while minimising solar heat gain, a balance needs to be achieved along with supplementary lighting to ensure long term health of plants.

Measuring indoor environment and productivity

Testing the indoor environment along with productivity requires a combination of quantitative and qualitative data. Australia's workforce is predicted to be valued at over $100 billion, with just a 1% change in productivity worth AUD $1.2 billion.[cxiii] However, the actual measurement of this percentage in the workplace is extremely difficult. Leaman and Bordass (1999)[cxiv] examined which design and management controlled workplace features influence productivity. They emphasised how complex buildings are and that individual variables are difficult to measure. Some scientifically supported evidence is appearing but occupant satisfaction is, as mentioned in the previous section, often measured through a self-assessment questionnaire which does not necessarily offer stringent enough results that can be applied to multiple organisations.

Occupancy surveys

There are several pre and post-occupancy surveys that have been used around the world to assess buildings. Few of these have pulled together and cross-analysed sustainability. Mostly they are given as questionnaires where occupants self-rate productivity. The New Buildings Institute in the US published a paper that reviewed a number of these studies, and the benefits and constraints the Institute identified are listed below:

<u>*PROBE - (Building Use Studies, UK)*</u>

Developed in the UK by Adrian Leaman, the BUS (Building Use Studies) surveyed building users in the UK between 1990-2008, it is now known as 'ARUP Appraise'. The study uses 12 variable indicators with subgroups by which it assesses occupant satisfaction: temperature (winter and summer), air, lighting, noise, comfort, needs, image, perceived productivity, and health. Leaman found that from the 1990s to the 2000s the following changes were observed in buildings[cxv]:

- Comfort conditions appear better but thermal comfort is still problematic.
- Perceptions of noise are improving.
- Perceptions of light have had some dramatic changes with people now saying there is too much artificial light.

The BUS tool has now been transformed into a tool used by ARUP to analyse buildings in operation with the aim of closing the feedback loop for optimal building performance.

Centre for Built Environment – UC Berkley

The Centre for Built Environment at University of California focuses on two main areas, researching the environment of occupied buildings and developing technology to improve the efficiency of buildings. They have developed an indoor environment survey that has been used around the world to assess the performance of occupied buildings. The survey focuses on seven areas of indoor environment performance: thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout, and office furnishings. It is a web based survey and is detailed enough to rate the comfort of each factor and then identify what any discomfort can be attributed to, and this can assist in analysing design features of buildings. Individual building features can also be rated individually.

University of Montreal – New Work Environment Research Group (GRET)

This group commenced in 2000 and focused on human use of interior space. Director, Dr Jaqueline Vischer, has developed building post-occupancy studies. Vischer equates productivity with comfort, and specifically three kinds of comfort that need to be measured: physical comfort, psychological comfort and functional comfort. These are outlined in the table below[cxvi]:

Table 4: Comfort in the workplace (Vischer 2008)

Physical comfort	**Psychological comfort**	**Functional comfort**
Health and safety Responsible design Building and construction standards Comfort standards	Sense of privacy Social vs. individual space Individual control Job and social status	Workspace design to support task performance

GRET has conducted surveys around the world, typically examining the areas of thermal comfort, light/glare, air quality, windows, workstation size-space-comfort, noise, privacy and the building overall. The main disadvantage of this survey is that it does not analyse the building in as much detail as the CBE studies. For example, CBE has questions on the use and effectiveness of motion sensors, louvres etc, whereas the GRET survey is mainly a 5-point scale measuring satisfaction.

Formulating a Building Performance Evaluation (BPE) framework

Most evaluations of buildings will combine a questionnaire such as the above mentioned occupancy surveys with tests on the building performance. In Australia, CETEC, an indoor environment testing organisation emphasise that productivity cannot be estimated from any one point, such as the occupancy surveys mentioned above. In order to achieve reliable results CETEC measure objective and subjective indicators through health and well-being questionnaires, a review of financial KPI’s and physical measurements on indoor environment. CETEC’s indoor environment quality assessments identify air quality, light and outlook, acoustic comfort, radiation, décor and layout and ergonomics as determinants of occupant health, productivity and well-being[cxvii]. Using this combined method CETEC conducted a pre and post occupancy study on a consulting firm in Melbourne. In addition to the questionnaires and financial review, physical measurements included thermal comfort, air quality, lighting (LUX) and acoustics (DB). Findings are outlined below.

Table 5: CETEC IEQ results (Garnys 2009)

	Thermal Comfort			Air Quality					
	Air temp. (°C)	Relative humidity (%RH)	Air movem. (m/sec)	Carbon dioxide (ppm)	Carbon monoxide (ppm)	Dust particles (mg/m^3)	Airborne microbials (cfu/m^3)	Form (mg/m^3)	VOCs (mg/m^3)
PRE	24.7	38.8	<.1	999	<1	.005	343	.03	.28
POST	23.3	51.6	<.1	605	<1	.008	213	.01	.05

Lighting (lux) increased, as did acoustics, to a point outside of recommended guidelines. Overall satisfaction was shown to increase as was productivity. Questionnaires were given to ascertain satisfaction levels, and productivity was measured through questionnaires and financial statistics. This is a positive and transparent result that would be welcomed by the industry on a larger scale. CETEC are now extending this research to 100 buildings internationally.

Judith Heerwagen has demonstrated the use of the University of California's Centre for the Built Environment (CBE) survey that has often been used to measure occupant satisfaction and employee productivity in a range of international studies. It is a web-based survey that measures office layout and furnishings, thermal comfort, air quality, lighting, acoustics, cleanliness and maintenance. Judith Heerwagen conducted a number of studies using this framework, one of which was a post-occupancy study on workers of the Philip Merrill Environmental Centre building in Annapolis, Maryland.[cxviii] This was conducted over a four-year period post-occupancy, with the surveys having a 78% response rate. Heerwagen also conducted a study of the Herman Miller SQA building in Michigan[cxix]. This research differed from many studies in that employee surveys were conducted pre and post move (rather than in retrospect). Overall the results were positive, with the social environment rated as better and the company reported an increase in productivity of 0.22% through improved on-time delivery and product quality. For the office workers it showed that 40% said there was no difference between workplaces with acoustics being the largest negative factor. A strength of this research is the actual measurement of productivity through output. Product or customer service measurements can show quantitative evidence of variations. The author emphasises the point that one building is insufficient to evaluate the effectiveness of green building and that a comparative database needs to be established. This is highly applicable to the SBE project in that several buildings need to be included in the process to ensure the most reliable results.

A comprehensive research framework was established in a study by Ries, Bilec at al (2006)[cxx] which demonstrated the use of quantified building and occupant data collection related to productivity. The study focused on the US company Castcon Stone as they relocated from a conventional 17,000 ft^2 facility to a new 37,000 ft^2 green designed facility. An investigation was conducted into the relationship between the cost of green building features and the long-term benefits, such as employee productivity gains, reduction in health and safety costs, and savings from energy, maintenance and operation.

The research methodology was both quantitative and qualitative, with data collection and analysis of both the old and new facilities over 12 months. This included performance surveys, focus groups, data collection, statistical analysis, interviews and observations. Meetings were conducted with the owner to understand facility layout, office and plant operations, data availability, company policies and design decisions. The results showed the staff perceived the new environment as superior for working conditions and that productivity improved, however absentee rates increased. High satisfaction results may be attributed to the novelty of the move rather than the actual environment. This shows a positive framework for data collection, but it is necessary for this to extend to the inclusion of actual data on the indoor-environment (such as temperature, IEQ, VOC levels) to correlate against staff perception

A similar framework was used by Singh and Syal (2010)[cxxi] when they examined the effects of improved indoor environmental quality on perceived health and productivity in occupants who moved from conventional to LEED rated office buildings. Two case studies were used in which employees were given pre and post move web-based surveys. These examined employee perceived asthma, respiratory symptoms, depression and stress conditions, and the effect of these changes on self-reported absenteeism, work hours and productivity. The pre-move surveys were given retrospectively 3 to 4 months after the move, and the post-move 3-4 months later. Overall reductions were found in self-reported absenteeism and affected work hours as a result of improved health and well-being, and increases in productivity.

There are several limitations of this research that appear in many similar studies, which should be noted when developing frameworks for future studies. Firstly there were no tests on indoor air quality conducted to correlate against the survey findings. Secondly, the pre-move surveys were conducted after the move relying solely on recollection. Thirdly, there were no records of illness or absenteeism to measure against the self-reports. Fourthly, there is seasonal bias which can impact allergies. Finally, because of the short time in which the surveys were conducted after the move, employees may still be excited and not able to properly rate productivity over the long term. The weaknesses in this study emphasise the importance of well-planned and long-term study.

Productivity is difficult to measure in an office environment. Unlike a manufacturing or industrial building, there are not exact outputs to measure (such as Castcon's measurement of concrete). Even when examining financial records for a company, there are many external variables, such as new contracts increasing revenue or new organisation policies. These can increase organisational productivity and it is difficult to isolate single variables.

Physiological measurements of productivity

A person's response to their working environment can be shown through physiological reactions. Dr Esther Sternberg has led some very relevant research in this area indicating the link between neuroscience and architecture, with a relation between how people perceive their environment and the impact on cognition, problem-solving and mood[cxxii]. Sternberg cites research that has indicated factors such as spatial design, texture, colours, lighting, density and noise can trigger stress responses[cxxiii], which in turn can impair decision making . Although this research is complex and requires medical expertise, it is very important in delivering transparent quantitative data on effective urban design.

Sternberg demonstrates that it is possible to measure a human's emotional response to space to establish positive and negative design features. Some of her work measured the environment's impact on stress levels in traditional verses modern office spaces through monitoring heart rate levels and cortisol. Although heart rates were elevated in the office and at home, these variations did not show up in the self-assessment questionnaires. She indicates that there are not sufficient measures in place to demonstrate whether (and how) green building influences the productivity of workers[cxxiv].

US research has been conducted into active living. The American Institute of Architects contributed to the New York 'Active Design Guidelines' which were formulated to provide architects and urban designers strategies to link evidence from health and environment related research into their practices[cxxv]. These guidelines are formed based on evidence that buildings which are designed to promote physical activity also influence the health and well-being of occupants. For example, stairs and other arrangements that encourage movement during the day, as opposed to sitting at a desk for 8 hours, may increase productivity. Managers may well be seeing increases in productivity and well-being in staff. But in order to convince a largely sceptical market on worthwhile investment into green building, it is vital to link human performance together with proven statistics. There is little research in this area and would be welcomed by the industry. The challenge will be finding a team that can provide the necessary expertise to bring together the medical, architectural and economic data.

Strategic Area 2: Energy and water performance of buildings

There are few assessment methods for environmental performance of buildings in operation that are used in conjunction with green rating schemes. Green Star does not have any mandatory monitoring for buildings to demonstrate actual energy and water savings, although GBCA are in the planning stages of a Performance Tool, which will rate a building based on its performance over a 12 month period. This tool will be in addition to the existing InDesign and AsBuilt tools. After scrutiny in this area LEED have implemented tighter energy reduction standards to monitor and record energy consumption. Under the new version 3 of LEED, building owners are now required to record energy usage and report it to the USGBC, and have a plan in place if improved energy saving is needed[cxxvi].

Australia has conducted some research into benchmarking tools. The MABEL and Probe tools have been used in several studies and are effective tools to monitor the total performance of a building linked with occupant satisfaction. NABERS is also a benchmarking tool that has previously been a voluntary program for building owners to rate their building's energy, water, waste and/or indoor environment. For buildings over 2000m^2 being leased or sold energy disclosure is now mandatory under the Commercial Building Disclosure legislation[cxxvii].

Energy Consumption

The Low Energy High Rise project was conducted by the Warren Centre in Australia[cxxviii]. The study looked at factors affecting energy efficiency in commercial buildings. This wasn't specific to green buildings, but is important to examine to see what maximises and minimises a building's energy performance, particularly as this can have a flow-on effect to other areas of performance for a building. The study included 127 buildings, where base building and tenant surveys were conducted. Buildings used had a bias towards higher quality buildings, the sample was not reflective of the actual population.

Some key findings of this study were:

- the age of the building did not necessarily reflect its energy efficiency but the worse the technology used the lower the efficiency;
- greater involvement of building management and tenants brings lower energy use;
- buildings perform better where there are energy efficiency training programs and skilled building managers;
- improvements can be made with low capex investments.

Overall the study found that buildings can achieve a four star NABERS rating with limited refurbishment, making a significant impact on Australia's greenhouse gas emissions, as well as building owners and tenants budgets.

A smaller scale study was performed in Sydney looking at peak load characteristics of commercial buildings. Buildings with best practice energy performance had a 26% lower peak energy demand, and 57% lower electricity consumption compared to average buildings. This is quite significant considering large electricity users pay about 13% of their bills to cover peak energy charges[cxxix].

One of the most interesting surveys on energy use in green rated buildings was conducted by Newsham et al[cxxx] in 2009. This study assessed the viability of a previous LEED commissioned study by Turner and Frankel (2008)[cxxxi] that found LEED certified buildings demonstrated energy savings. Newsham et al re-analysed this data which had compared energy consumption from 100 LEED certified buildings to averages from the US national building stock database. Newsham et al's study matched the LEED buildings to similar buildings in the database in terms of type, age, size and climate zone. It also considered the type of LEED accreditation. Newsham et al found that on average LEED buildings used less energy per floor area, but when compared to matched building 28-35% used more energy. No evidence was found to support that silver or gold accredited buildings perform better. It showed that green buildings can achieve energy savings, but more work is needed on the rating scheme. This is a significant study showing the importance of matching building types to ascertain the most reliable results. The US Green Building Council (USGBC) were taken to court following the Turner and Frankel report in a dispute that LEED does not deliver high performing buildings, however the case was dismissed.

Studies assessing actual energy performance of low energy buildings were conducted by Bordass[cxxxii] (2010) in the UK and Torcellini et al[cxxxiii] (2005) in the US. Both studies found that buildings performed more efficiently than conventional buildings, but still performed lower than the planned outcome. For example, Bordass found that:

– Higher than expected fuel for annual heating was used, attributed to high air infiltration, poor control, avoidable waste due to mis-matched system and user.

– Higher than expected electricity use which was attributed to more electrical equipment installed than designers anticipated (and operating for longer), building used for longer hours, more mechanical ventilation and cooling, ICT and other equipment (i.e. vending machines) not properly accounted for in design.

– Lighting energy was higher than expected attributed to poor usability for manual control, ineffective daylight links, poorly designed daylit areas, better management systems.

Torcellini et al (2005)[cxxxiv] assessed the energy use of six high performance buildings in the US in comparison to their original design goals. One year of data was collected from energy flows including lighting loads, HVAC loads, and plug loads. The buildings performed more efficiently than conventional buildings, but below the intended design goals for energy consumption. Both of these studies indicate the need to test all aspects of a building post-construction. The causes for energy inefficiency were found to not only be technical problems, but also tenant related issues and specific occupancy requirements, as well as the need for better building management systems. This allows for identification of specific areas needing improvement and lessons learnt for future buildings. A study conducted in 2001 by Bordass, Leaman & Ruyssevelt[cxxxv] evaluated green buildings 2 to 3 years post construction found similar results to Bordass's 2010 study, suggesting there has not been a significant progress in improving environmental performance of buildings post-construction.

Investa own and operate over 1 million square metres of commercial office space in Australia. They commissioned a study (Roussac, 2009[cxxxvi]) to examine and implement energy efficiency plans in their buildings. 11 buildings were selected over 10 years of age, with a mix of age, location, size and operating platform. A baseline was established in 2004 and evaluated against this annually until 2008 bringing an energy use reduction of 29%. A positive correlation was found between occupants hot/cold complaints and energy use, complaints decreased as efficiency improved. This study suggests that energy efficiency and occupant satisfaction are possible in existing buildings, requiring a combination of technical and management interventions.

It is possible to increase the energy efficiency of a building and at the same time improve the indoor environment. Fisk (2000) gives a list of possible energy efficiency measures than can be taken to improve indoor environmental quality.

Table 6: Energy efficiency measures and influence on IEQ

Energy efficiency measure	**Influence on IEQ or productivity**
Energy efficient lamps, ballasts, fixtures	Improved lighting quality and occupant satisfaction. Productivity may increase when work is visually demanding.
Outside air economizer for free cooling	Generally, indoor environmental quality will improve owing to increase in average ventilation rate. Potential productivity gains from reduced respiratory disease and sick building syndrome (SBS).
Heat recovery from exhaust ventilation air	If heat recovery allows increased outside air, indoor environmental quality will usually improve. Potential productivity gains from reduced respiratory disease and SBS.
Night time pre-cooling using outdoor air	Night time ventilation may decrease indoor concentrations of indoor-generated pollutants when occupants arrive at work, leading to reduced SBS.
Operable windows substitute for air conditioning	On average, occupants of buildings with natural ventilation and operable windows report fewer SBS symptoms.
Increased thermal insulation in building envelope	Potential increase in thermal comfort because insulation helps heating/ventilation/air conditioning system satisfy thermal loads and because of reduced radiant heat exchange between occupants and building envelope.
Thermally efficient windows	Improvements in thermal comfort from reductions of drafts and radiant heat exchange between occupants and windows. Reduces condensation on windows and associated risks from growth of microorganisms.

Source: Fisk (2000)[cxxxvii]

There is no doubt that the losses from productivity can far outweigh the energy bills for a building. It is necessary to find a balance between the most efficient technology that also provides and safe and healthy working environment. The measurement of energy use in buildings is relatively easy compared to productivity and occupant comfort. Data provides solid evidence of energy consumption of a building in operation and can be compared to the expected consumption if the building is new.

Water consumption

It is interesting to note the lack of research into water consumption within the built environment. There are mixed opinions within the industry as to whether this needs to be a priority. Lester Brown, president of the Earth Policy Institute emphasises the over-consumption of water around the world, and that due to a low price it is treated as an abundant resource[cxxxviii]. There has been more of a focus on residential homes for water efficiency but not as much emphasis to non-domestic buildings. Energy and water are co-dependent through heating and pumping, and HVAC systems can also have a significant impact on water consumption as well as carbon emissions through energy use and refrigerants.

Technologies

The selection of technologies in buildings reflects highly on the energy and water performance. Tradition leads many decisions for technologies, in particular lighting and air-conditioning. People are accustomed to, and therefore expect, certain light and thermal comfort levels. Yet society has behavioural change issues when attempting to change set point temperatures in buildings, often clients demand a sufficient air-conditioning system and from design through to installation an extra 10-20% in capacity has been added to ensure client demands are met. This means the system is larger and more energy intensive then necessary, and also more difficult to control, potentially leading to higher complaints regarding temperature. How can one get around this? Brett Pollard (Mind the Gap 2008) suggests that including users and operators of buildings in the design will assist. For example, if a tenant can see the issues an air-conditioning engineer has with controlling an over-sized system and the resulting impact on heating/cooling complaints and energy consumption, perhaps they would be more informed and demands on building design would not be unrealistic.

Inclusion in Building Performance Evaluation (BPE) Framework

It is necessary for a study to combine energy and water data with measures of indoor environment quality and occupant productivity and satisfaction to give a reliable assessment of a building's sustainability. The types of technologies and use of these in a building can influence its total energy and water performance, so where possible it is helpful to access sub-metred data. Many new buildings have this capacity but it may be more difficult to calculate specific energy and water loads of individual technologies (such as HVAC systems) in older multi-tenanted buildings. Where possible it is also important to observe the base building verses tenancy consumption as these can be quite varied depending on building services, fitouts and behaviour of tenants

Strategic Area 3: Building Management and Tenant Behaviour

Often neglected in studies measuring building performance is tenant behaviour post-construction or retrofit. For example, a study is currently being conducted in the UK into why lights are left on in London's workplaces at night and what can be done to address this problem. Lighting accounts for eight percent of London's emissions annually, and the Carbon Trust estimate that bills could be cut by 15% if they were used only when genuinely required[cxxxix]. Looking out over any of Australia's capital cities at night reinforces that tenancy behaviour is absolutely essential to a building's level of sustainability. Methodology into the process for this London study is not yet available but the results could be a benchmark for all cities and integrated into building education and management. Europe shows many behaviour change programs and energy efficiency initiatives, some of which are backed by the European Commission or other joint partnerships with public funding. A research project called 'Changing Behaviour' has analysed the success of European energy demand-side programmes to build a tool-kit on how to create energy behaviour change programs. Some of the non-domestic programmes analysed included[cxl]:

– Energy Trophy (Hungary): Competition for saving energy in office buildings through change in employee behaviour.
– Metropolitan Police Energy Efficiency Programme (UK): Improve energy efficiency in existing buildings and practices of the Metropolitan Police Service
– Green Office Program (Finland): Certification and management scheme to reduce CO2-e and resource consumption in offices
– Manchester is my planet (UK): Increase policy development/ implementation on Climate Change among Greater Manchester local authorities

The 'Changing Behaviour' study identified the key stakeholders in office behaviour change programs, but emphasised that no two programs are identical and it is important to be flexible. Another interesting point was that pilots and up scaling of small projects were successful, and user-involvement in developing the programmes can create lasting change in energy-use patterns. Steinberg et al (2008)[cxli] conducted research into training manual requirements for LEED certified green buildings. A list of behaviours was developed to support the LEED accreditations, with a questionnaire sent out and focus groups conducted. Results found that staff were active in waste reduction but not in energy efficient actions. They were unclear of what was required. This research is important in the training process, for tenants to change their behaviour they need to know what to do, and designs should reduce the ability for inefficient behaviour, such as switching to sensored lighting.

Strategic Area 4: Economic Performance of Buildings

The most significant study into the economic value of green building was conducted by Eichhholtz, Nok and Quigley in 2008 titled 'Doing good by doing green'[cxlii]. This US study compared the rental rates and selling prices of LEED rated and Energy Star buildings to conventional buildings. It found that buildings with green ratings on average commanded a 3% higher rental return and a 16% higher selling price. Another US study recently released by McGraw-Hill Construction, CBRE and the USD Burnham-Moores Centre for Real Estate[cxliii] showed that sustainably managed building owners expect a 4% higher return on investment; 5% increase in building value and occupancy; 8% drop in operating costs; and 1% rise in rental income.

However, there are still mixed views on the physical property value and as it is a relatively young market in Australia the results may not yet be tangible. In 'Does Green Pay' a report by Citigroup Global Markets (2010)[cxliv], Elaine Prior reviewed studies[cxlv,cxlvi] and found no solid evidence in the Australian market that green buildings are linked to increased property values. An Australian version of the 'Doing Good by Doing Green' report has been commissioned and will be conducted by the University of Western Sydney (UWS). Until the UWS report is conducted there is no solid evidence in Australia that green building is associated to higher real estate values. The financial performance of green buildings must also be considered through staff costs. Davis Langdon have conducted research emphasising how important staff satisfaction is as 80% of a business's costs come from staff, and on average it costs $16500 when losing and replacing a staff member. Their studies found that investment in green building can increase staff productivity by 1 to 3%[cxlvii]. However these studies were based on simulated models. Several studies in section 2.2 outlined productivity results, such as the CETEC study conducted pre and post occupancy of a 6 star Green Star rated building which found that productivity gains equated to $1 million per annum ($5000 per staff member)[cxlviii].

It is important when looking at studies into financial performance that a wide data set is used over a 2 to 3 year time period. The CETEC study is for a very small sample and productivity may vary after the first few months of occupancy, particularly as tenants change. The other important element of financial performance is the associated cost savings from the efficient energy use outlined in the previous section on environmental performance. It is important for 'savings' to be proven. For example Guyon (2006)[cxlix] found the use of natural lighting in schools reduced energy consumption by 64%, with a 4.2 year return on investment. However this reduction is given as a comparison to simulated consumption, which leads into a repeated problem of simulated verses actual energy consumption. These studies do show the potential for increased real estate value, staff productivity costs and savings from energy efficiency. The performance of green rated buildings in Australia will be demonstrated over the next 12 months as data is collected from the CBD scheme and more quantifiable evidence will be available regarding the economic value of green buildings. This has the potential to prove whether a Green Star certification is as valuable as a NABERS rating.

Strategic Area 5: Achieving Triple Bottom Line Results

A triple bottom line approach to the design of buildings has the potential to lower the Australian commercial building industry's contribution to GHG emissions by 30-35 percent[cl]. *The question is how successful are the existing green building programs in achieving triple bottom line results?* There have been several studies into LEED and BREEAM which have mainly quantified the success based on immediate financial return from investing in green accreditations. One such study showed a three percent higher rent value and improved productivity in staff[cli]. It is important that the results are demonstrating a combination of environmental, economic and social benefits.

There has been much international criticism on the sustainable outcomes of green building certifications. By all means the GBCA has made a tremendous impact on the development of green building in Australia and has the MOU with the UNEP's Sustainable Building and Climate Change initiative to introduce a common intentional carbon metric to support emissions reduction in the building sector at international, national and local levels[clii]. These types of initiatives will continue to push the green building market forward. However, there comes the question of whether the accreditations are becoming PR driven marketing opportunities for companies that can afford the certification processes. An article by Auden Schendler called 'Top green-building system is in desperate need of repair'[cliii] brought attention to this when analysing the LEED program. He stated that the program has become an 'expensive, slow, confusing and unwieldy' process driven by PR opportunities and is resulting in certification being a priority over environmental responsibility. Critics of Green Star say that the program concentrates too much on credits, which may inhibit the actual performance potential for designs. Developers are not looking at how the building can best perform environmentally and socially over the long term, but rather how the building can be designed to obtain the Green Star credits. As there is now speculative evidence that owners will pay more for Green Star accredited buildings, designers are forced to 'credit shop', turning Green Star into a compliance tool rather than one that encourages innovation.

LEED receives some of the same criticism as Green Star for credit shopping. Schendler's article indicated the high expense of receiving an accreditation with little flexibility for the most environmentally beneficial designs. A participant from a study performed by the Green Building Alliance was quoted in the article saying '*In a recent building, we received one point for spending an extra $1.3 million for a heat-recovery system that will save about $500,000 in energy costs per year. We also got one point for installing a $395 bicycle rack'*. The credits for both LEED and GBCA do not seem to be built on any performance data, which comes back to the saying 'you can't manage what you can't measure'. This lack of performance data comes from few requirements within the programs for proof of sustainable performance. Organisations such as the International Sustainability Alliance are making developments in this area, UNEP-SBCI are also working towards developing the previously mentioned Common Carbon Metric. The difficulty with producing any international standards and benchmarks are climatic, cultural and financial variations. For example, the WBCSD Energy Efficiency in Buildings compared energy use across a number of countries but it is difficult to make cross-country comparisons, particularly when a large amount of energy consumption in buildings comes from heating and cooling systems.

Environmental implications

There are several environmental implications of green building rating systems. The central issue is that the rating systems are assessing the intended performance of a building. Another main issue is that the effectiveness of green building may actually be limited by the accreditation requirements. For example, some states in Australia are disadvantaged by limited access to recycling facilities and cannot achieve the allocated Green Star points.

This leads to the much larger issue extending outside of a building's performance, which is environmental accountability. Australians (in general) still do not seem to perceive buildings as large contributors to climate change. Maintenance of comfort, convenience and lifestyle standards dominate behaviour and habits[cliv]. How is it possible that buildings are still being constructed neglecting environmental consideration? Perhaps a vital element missing from green building rating schemes is environmental accountability of natural resources. This is why NABERS is more reliant for actual performance rating, it measures energy, water and waste. NABERS also covers existing buildings. Australia has an aging building stock and retrofitting for energy efficiency is vital. Western Australia currently has a 10% vacancy rate in commercial buildings[clv], so before constructing new buildings it would seem to be more beneficial to improve the efficiency of current structures during a high vacancy period.

The environmental accountability for both NABERS and the rating systems excludes the impact of embodied carbon. According to the UK's RICS Research[clvi] the embodied carbon in an office building can be responsible for 45% of its whole life cycle emissions and a study by Scheuer in 2002[clvii] found that LEED 'does not provide a consistent, organised structure for achievement of environmental goals' by excluding embodied carbon. This area is complicated and difficult to establish benchmarks for, but research is emerging which can provide guidance for the industry. For example, a study by the New Zealand Ministry of Agriculture and Environment[clviii] gives total emissions from the LCA of four types of multi-storey buildings. This benchmark data needs to be accessible to developers and should eventually form part of green building certifications.

Social implications

A balance is needed between environmental and social factors for green building. For example, some green rated offices are being designed with hot-desking, which allows various people to share workspaces and also work from home, which can improve quality of family life. In addition, design that improves indoor air quality could reduce illness in workers, resulting in greater cost savings over the long-term for the health industry, as well as improved productivity for the companies.

The social benefits need to extend beyond improved staff productivity. According to Boyd and Kimmer[clix] the benchmarks to measure social sustainability need to take a wide view. Below is the list that they give on suggested social benchmarks for green building:

- Health and safety
- Stakeholder relations
- Community engagement
- Accessibility

- Occupant satisfaction and productivity
- Cultural issues
- Local impacts

The social implications again come back to the attitude and behaviour of people. Organisations and individuals need to be adaptable and overcome social norms and expectations. For example, a Homebuyers advertisement promotes 'Why buy second hand when you can have a new home'? A new home in Perth means environmental impacts from construction, embodied carbon, land use, operational emissions and potentially contributing to the urban sprawl. In addition, most residential homes are not built with additional ESD considerations (such as solar passive design, rainwater tanks, solar etc) due to increased expense. This attitude extends to workplaces with the habitual expectation of temperature and air-conditioning, rather than opening up windows.

Green commercial building needs a holistic view. If a grey water system is installed in one building, what are the long term implications and how is that benefitting the wider community? Green Star is targeting this with development of the 'Precincts' tool. One area where this is being applied is Victoria Harbour in Melbourne. A 20 year agreement is in place between LendLease and land owner VicUrban to sustainably develop up to 350,000sqm of commercial office space, 22,000sqm of retail space and over 2000 apartments[clx].

As noted by Heerwagen (1999)[clxi], in relation to indoor environment, society seems to know more about what makes people sick than what makes them healthy. It is important that results from future studies into the indoor environment and health and well-being of occupants do not merely re-state past findings as there has been a wide range of studies in this area. The human element of working in green verses traditional buildings must be integrated with environmental and economic factors. Economic returns can be made from improving staff productivity but if this is the main driver for improving occupant satisfaction, it is neglecting the intention of sustainable building. Green building can potentially bring social benefits both inside and outside of the workspace.

Economic implications

The Green Building industry is lucrative. GBCA values the Australian market at $21 billion AUD[clxii], with McGraw-Hill estimating an international value of $60 billion USD[clxiii]. There are several articles and studies reporting the financial benefits of green accreditation for commercial buildings through increased real estate value and staff retention and productivity. Although there is evidence of improved value for green rated properties, the lack of energy performance data questions justification of this price increase if an accredited building is not actually performing any better than a conventional building. This indicates the marketing and PR drivers behind the accreditations. The CBD mandatory disclosure now requires the NABERS rating to be included with all real-estate advertisements. As this data becomes available it will be an interesting time for green real-estate in Australia, and will show if purchasers prefer an actual energy efficiency rating or a Green Star rating.

On average it costs around $100,000 to $150,000 for a 5 star Green Star accreditation, and as much as 2 or 3 times this for a six star, as well as the equivalent of one year full-time labour for completing the application[clxiv]. A sustainable building can be achieved without this extra cost. For example, Investa controls about 5% of Australia's commercial office space . They commenced their emissions reduction program in 2004 and by 2008 had reduced their emissions by 24%. Their NABERS energy rating has gone from 2.60 to 3.96 stars, bringing a $5 million dollar decrease in their energy bill[clxv]. The previously mentioned Davis Langdon findings were based on modelling, but how can tenant behaviour and building performance be reliably predicted? A building may install LED lighting, but if it doesn't improve the indoor environment by providing sufficient lighting it could need to be re-done, costing much more than predicted[clxvi]. Green accreditations finish at building handover and any of these ongoing issues do not seem to be recognised.

The uncertainty in Australia's green economy is holding back the potential for innovation in green building. Europe has supported innovation with the GreenBuilding Intelligent Energy program. Rather than organisations paying for an accreditation, they participated in a voluntary program that encouraged and awarded environmental innovation. Applied in Australia this could move the market from a push to a pull strategy. A comment was made at a GBCA 'Meet the Stars' conference, when a speaker commented that the four star Green Star rating was achievable and brought financial savings as well as good PR within the industry but that going above this star was more difficult, such as the use of grey water systems, and brought little financial gain but was more of a 'feel-good' initiative, so it is not as frequently pursued. The economic outcomes of green building are being viewed separately to the environmental outcomes. It is vital that these are interlinked and considered mutually dependent.

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