Developing a framework of interventions for retrofitting high-rise office buildings in warm climates

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ABSTRACT: There is a complex interplay of issues associated with retrofitting high-rise office buildings in warm climates. This paper explores non-technological and technological interventions for retrofitting and the potential environmental benefits associated with them. An approach is developed in the context of bioclimatic renovation design for existing high-rise office buildings in warm climates in Australia that offers opportunities for promoting energy-efficient practices through the exploitation of occupant behaviour, building design and powered systems in the commercial building sector.

Keywords: retrofitting, bioclimatic design, high rise office buildings, warm climates

INTRODUCTION

Fourth Assessment Report of International Panel on Climate change (IPCC) notes that continued GHG emissions at or above current rates would cause further warming and induce many adverse changes in the global climate system (IPCC, 2007). Warming climates increase environmental loads into the buildings resulting in higher internal temperatures in buildings and studies have shown that this relationship is linear (Coley et al, 2010). Furthermore, predicted increase of extreme air temperatures due to climate change effects in Australia may considerably impact on the electricity demand (Howden SM & Crimp S, 2001; Guan.L, 2009) and thus emissions. With the projected increase in energy use and the demand for more comfortable indoor environments in offices, there is a growing concern about high energy consumption in commercial buildings and its likely adverse impacts on the environment.

In Australia, annual energy consumption for office buildings was around 170 KWh per m² in 2006 (Cheung 2006) but it has continued to increase. National Greenhouse Gas Inventory of Department of Climate Change shows that in 2008, the total emissions estimated for the four quarters up to December was 553 Mt CO₂–e. This is an increase of 1.1 percent compared with the corresponding period for the previous year, 2007. Energy consumption in buildings accounts for approximately 20 per cent of Australia’s greenhouse gas emissions – split equally between commercial and residential buildings. Therefore, there is increasing pressure on all stakeholders to introduce energy efficient practices in the building sector and alternative sources of supply of electricity (Warren Centre 2007,) in order to comply with the Kyoto Protocol of 2008 and the subsequent Copenhagen Accord which is intended to supersede the Kyoto Protocol in 2012.

The study seeks literature-based evidence to support retrofitting existing commercial high rise buildings involving both non-technological and technology based interventions that prove cost effective and also those that could make improvements to lower energy use, GHG emissions and operating costs.

1. EXISTING COMMERCIAL BUILDINGS

1.1. Energy efficiency gap

With the expected 64 Mt of carbon dioxide emission due to commercial building sector in 2010 (AGO, 1999), a great majority of existing commercial high rise building stock in Australia is found to be carrying a high potential for cost effective energy efficiency opportunities (Warren Centre, 2007). The Warren Centre study found that the average annual energy consumption in a sample of buildings fell between 230-270 KWh/m². With a large proportion of existing commercial buildings in CBD office markets being over 20 years old (LaSalle, 2010) and high energy consumption patterns, the majority of commercial properties approach obsolescence posing a serious threat to efforts in emission reduction targets. This LaSalle study found a need to focus on at least 80 percent of the older stock where retrofits provide greater opportunities to achieve meaningful emission reduction targets than on improving new building stock.

1.2. Asset value of commercial properties

The drivers for undertaking renovation in which energy efficiency is improved will depend upon justifying the financial wherewithal for its undertaking. This will depend on the financial benefit outweighing the cost, and this will in turn
depend upon the demand for better performing buildings. The two major classes of drivers are then the 'push' of legislation and /or the 'pull' of financial and environmental benefits.

The push of legislation includes the provision of minimum standards (BCA, 2004), global Environmental Treaties and the Australian Government Accommodation Policy. The 'pull' factors include the time horizon and economic benefits to the building owner, and environmental issues.

Asset value of a commercial property plays a key role in the evaluation of decisions leading to optimum financial returns where the built asset represents a significant proportion of the owning organisation’s wealth. However, concern for life-cycle costs depends on the owner’s involvement with the users as designing value enhancement into the building operation to improve financial performance is important only if it benefits the party initiating the renovation (Leifer, 2003). A government report suggests that office buildings in major CBDs in Australia require a major refurbishment every 20-25 years (NPWC, 1988). In this context environmental performance is increasingly becoming a driver as tenants seek current standards in the space they occupy (LaSalle, 2010).

1.3. Improving energy efficiency
In respect to environmental performance standards in present buildings, AGBR's National Australian Built Environment Rating system (NABERS) rating of no less than 4.5 stars or achieving Green Star rating is increasingly becoming an expectation. With the most new buildings achieving sustainability credentials, owners and tenants of office workplaces of more than 2,000m² in existing buildings are required by law to show their measured energy performance rating on the buildings that they own and occupy (LaSalle, 2010).

Further, improving the energy efficiency of existing commercial buildings is definitely the most significant action the present commercial building sector can take in its direction to reduce Australia’s dependency on non-renewable energy resources and GHG emissions. Since energy in these buildings is consumed mainly for cooling, heating and lighting (LaSalle, 2004) while a significant portion is used for equipment, integration of energy conservation interventions requires the knowledge of specific energy related characteristics. These characteristics may include technological and non-technological aspects.

2. BUILDING CHARACTERISTICS AND TYPOLOGIES
Building characteristics both physical and non-physical are important parameters affecting energy use behaviour of a building. The effort to understand energy related characteristic of existing high rise commercial buildings requires the recognition of building type - a form or character that distinguishes a group of buildings, and a typology, the study of building types.

In high rise buildings with tall facades having small roof area in relation to external facade area, the heat transfer between indoor environment and outdoor climate is significant through the fenestration of facade. Three ways of environmental and internal load transfer are considered – conduction through the opaque surface, conduction through glazed areas and radiation through the glazed area. Lam’s (2000) study using a DOE simulation based on a generic model across 146 existing high rise commercial buildings in Hong Kong suggests following as major design aspects that affect building cooling loads specially in warm climates.

1. Building envelope
2. Indoor design conditions
3. Internal loads and
4. Heating ventilation and air-conditioning (HVAC)

As these areas are inter-related retrofit attempts need to span all four. Dascalaki et al (2002) have categorised buildings in respect to the degree of exposure for renovation purposes in terms of thermal mass, skin dependence and internal structure. Thus office buildings can be:

1. Free standing or enclosed, based on their location in the urban context
2. Heavy or light, depending on the structure and material of construction
3. Skin or core dependant, according to the relative importance of the outer envelope and the installed active systems in their energy performance
4. Open plan, consisting of large spaces and minimum partitioning or cellular, consisting of small spaces (Dascalaki et al, 2002)

With energy performance improvement as the main target of retrofit intervention, these typologies were found to influence various levels of interactions in the building-climate relationship and control the indoor building environments. Retrofit interventions can be effective in the following areas;

2.1. Bioclimatic influence of buildings
Bioclimatic influence of buildings (Olgyay, 1963) is seen as an appropriate basis for climate responsive design which involves the way buildings filter and modify the external climate for occupants’ comforts involving four equally

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important interlocking variables i.e. climate, biology, technology and architecture. In this process, the building envelope, section and form are main bioclimatic modifiers that can reduce negative impacts of outdoor air temperature, summer heat gain, winter heat loss, and optimise daylight efficiency and increase internal heat loss in summer.

These influences can be effective in skin dependant buildings because of the potential interaction between climate, buildings and occupants. Bioclimatic integration in new office buildings is highly visible, e.g. Ken Yeang’s work, but there is not much support of its effectiveness from empirical evidence. Nevertheless adoption of the bioclimatic approach in retrofitting is warranted in the context of environmental sustainability.


2.2. Active system efficiency of buildings in warm climates
The large amount of internal heat gain from occupancy, lighting, and environmental loads due to fenestration through the envelope of office buildings raises concern over the ability to reduce energy consumption. Core dependant buildings with internal load dominancy must depend on active systems for indoor climate control. Focussing on the operational stage of buildings, improving efficiency of energy driven active systems could result in significant energy savings. The study of Lam (2000) demonstrates that energy use due to internal loads from lighting, equipment and occupancy accounts for more than 50 percent of the total energy use in typical air-conditioned high rise office buildings. This review shows a trend towards a focus on issues such as improving efficiency of active systems, their operation and service in buildings.

Interventions that work well to exploit energy efficiency in active systems such as HVAC and lighting can be found in the retrofit attempts and work of Rahman et al (2010) and Stefano (2010).

2.3. Occupancy behaviour in building operation
Encouraging the building industry to adopt demand management through occupancy behaviour in building operations is also an approach that is effective. Energy audit information of office building characteristics (McGuire et al, 2009) have highlighted that during a typical day energy demand in an office varies with the occupancy hence the influence of occupants who can control their own lighting, heating and cooling on the energy consumption of buildings is profound (Steemers and Manchanda 2010). There is evidence that occupants in these controllable indoor environments are less prone to absenteeism thus increasing labour productivity (Santamouris, 2002).

3. PRIORITIZING INTERVENTIONS – solution sets for retrofitting
A retrofit intervention always offers potential for investigation with regard to criteria which simultaneously take into account multiple factors such as “architectural and engineering considerations”, “user requirement” and “economic impacts”. Each performance of interventions cannot be looked at in isolation but as a system as a whole. Prioritising multiple factors, delivering various benefits, offers an efficient possibility to compare and then prioritize the interventions in a building project from which a group can then form a solution set for retrofitting.

The multi criteria approach that was designed to rank different retrofit interventions by Rey (2004) is focussed on finding solutions sets that are technically appropriate, environmentally sound, financially viable and socio-culturally valuable. In order to do that, three types of possible areas or levels (strategies) are identified in respect to architectural and engineering considerations;

1. Stabilization strategy or minor retrofit
   Interventions that do not fundamentally modify the character, substance or appearance of the building are considered. Solutions in this group allow the quick and easy formulation of cost effective interventions which are quite straightforward in terms disruption to the building’s architecture and engineering technology. The Property Council Australia (PCA) outlines several quick ‘wins’ which can produce immediate benefits;

2. Substitution strategy or intermediate retrofit
   Substitution strategy consists of interventions that contribute a complete efficiency improvement to a particular energy related element or system and transforms simultaneously the substance and the appearance of the building (Rey, 2004). Substitution strategy distinguishes itself by a large degree of transformation to components of the building. In this case the interventions imply a ratio between cost and energy performance. PCA study (2009) presents a large amount of interventions with differing costs, benefits and sustainability outcomes.
3. Restitution strategy or major retrofit
   This major refurbishment strategy involves a complete transformation of building’s energy related characteristics and appearance but maintains a large portion of the original substance. The degree of intervention may vary with the building typology and the age of the building. A comprehensive manual of energy upgrades to services systems is offered in the CIBSE Guide F (CIBSE, 2004).

Costs of interventions, energy related building characteristics, climate of the building location and occupancy profile are important concerns in the selection of retrofit interventions to form solution sets. Further, different interventions present considerable variations in respect to energy performance. Therefore, there is need to have better means of comparison of energy benefits from different possible interventions. As shown in Figure 01 the extent of energy upgrades will depend upon cost. However, the financial feasibility will be amortised quicker where there is also an intention to improve the building’s image. This review on a multi criteria approach to selecting solution sets implies that ‘win-win’ situations will arise when all related stakeholders contribute to retrofit efforts. This addresses the framework for retrofitting high rise office buildings in the energy sustainability context and also provides new methodologies in understanding the process and then prioritizing of retrofit interventions.

![Figure 1: Framework for the methodology for energy retrofitting](image)

### 4. RESEARCH APPROACH

The research approach employs a case study to demonstrate a common typology of building. As Flyvbjerg (2006) shows Critical Cases provide evidence of more general characteristics of the issues of concern and contribute to the cumulative development of knowledge through the ability to summarize and develop the findings into general propositions and theories. Thus, the research aims to identify a typology with energy related characteristics of a critical case and then generalising the research findings as a source of scientific knowledge. This will help uncover an effective methodology from associations that address the critical case for retrofitting existing commercial high rise buildings.

Hyde et al (2009) see 160, Ann Street, Brisbane, in Queensland State, Australia (Fig 2A) as a critical case which embodies the problems of retrofit and renovation. The problem it typifies is that a large number of existing commercial buildings have become obsolete, including poor environmental performance. The deeper causes of the problem are the lack of integration of building design with the climate for indoor comfort, the inefficiencies in the active systems, the occupants’ unfavourable behaviours in operational aspects and effects of climate change.

#### 4.1. Methodology

The issues to be addressed through the case study are the specific environmental requirements that need to be met to achieve current benchmarks performance. The four stage retrofit methodology proposed by Hyde et al (2009) is used. The stages are:

1. Trend and system analysis of energy (and water) consumption of the existing building
2. Climate analysis and climate change effects on buildings
3. Identifying solution sets and areas involving retrofitting scenarios for the existing building in 4 paradigms i.e.
   - Paradigm One-external passive
   - Paradigm Two-internal passive
   - Paradigm Three-active systems
   - Paradigm Four-synergies of active+passive
4. Testing and evaluating the effectiveness of these retrofit scenarios in meeting current benchmarks using advanced computer based simulation program – DesignBuilder

The DesignBuilder computer based simulation program with graphical utility interface for EnergyPlus is used for performance assessment of the critical case. Performance simulation is aimed at reproducing actual building performance and comparing this to alternative design options based on performance standards and targets to achieve various outcomes including energy efficiency, thermal comfort, environmental benefits and economic feasibility. This paper presents the outcome with regard to energy saving targets. The energy simulation process of this research followed the following stages in order to maintain prediction accuracy:

1. Development of the model of the critical case considering the design, massing and orientation of the building and its context
2. Input of a more detailed description of the building in terms of thermal barriers, with thermal and lighting characteristics of the envelope, operating, and thermostat settings etc.
3. Modelling the critical case as the base case and validating the results against the actual performance measured onsite to ascertain the accuracy of the model.

4.1. Trend and system analysis of the Critical Case
Research Team carried out site visits, energy surveys in the case study building to determine the existing energy consumption level. Previous energy audit reports (ARUP, 2008) and energy consumption data for November 2007-November 2008 and November 2008-November 2009 were obtained for review, building energy characteristics and HVAC systems were surveyed and analysed.

The critical case study is found to have a high annual energy consumption ranging from 125KWh/m²/a to 157KWh/m²/a for HVAC and 247 KWh/m²/a for whole building. The energy end use breakdown of the total energy consumption includes tenancy 47% (lighting 18%, plug loads 29%), HVAC 44%, Lifts 5% and unrecorded 4% (Fig. 2). Major part of the energy consumption is due to heat gain through the envelope and inefficient use of HVAC system with poor air tightness in the envelope (Fig 2B)

4.1.2. Climate change effects on buildings
Queensland's annual average temperature has increased at a faster rate than the national average with the rate of temperature increase ranging from 0.07 Degrees C per decade in the far north to 0.23 Degrees C per decade in the south west of the State (Garnaut, 2008). The sub-tropical climate in Brisbane is expected to be a tropical climate in the future with mean temperatures above 30 Degrees C for nearly 30 days per year (Hyde et al 2009). The question therefore arises how this kind of climate change will affect the design of new and existing buildings. Hence, the research aims to evaluate the potential for additional strategies to cope with extreme temperatures. It also aims to establish that the buildings’ envelope plays a key role in adapting to climate change through the inclusion of new solution sets primarily involving passive climate control focussing on the form and fabric of the building design.

5. IDENTIFYING SOLUTION SETS
The case study is primarily a core dependant, open plan heavy structure. The main architectural and engineering characteristics of the building are:
1. Deep plan floor plates with glazed areas on the outer envelope to the north and south
2. Daylight penetration is insufficient for some working areas resulting in use of artificial lighting throughout the day. The installed power for tenancy (artificial lighting + plug loads) exceeds 1, 948, 244 KWh
3. The envelope including heavy fabric and glazed areas are not insulated for heat gain control in summers
4. The passive zone close to windows are not properly protected from solar gain and
5. The HVAC system is operating under a constant set point temperature

The following section presents two main scenarios that carry interventions.

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5.1. Retrofitting scenario
Retrofit interventions were primarily an outcome of the critical case review following the bioclimatic design approach (Olgyay, 1963) which deals with building interior and exterior. In the two intervention scenarios non-design based and design-based interventions are listed in Tables 01 and 02 respectively.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Literature/Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set point temperature</td>
<td>Increase of the summer set point temperature by 1 Degree C from 23 to 24</td>
</tr>
<tr>
<td>Reduction of infiltration</td>
<td>Reduction of infiltration by weather stripping of windows in the external envelope to prevent heat gain in summer and heat loss in winter</td>
</tr>
<tr>
<td>Daily occupancy and</td>
<td>Use of fractional schedules of BCA Section J for occupancy, artificial lighting,</td>
</tr>
<tr>
<td>operational profiles</td>
<td>appliances and equipment and air-conditioning for typical office activities in 18 floors</td>
</tr>
<tr>
<td>Ventilation (Tune-up/minor</td>
<td>Improvement of natural ventilation by opening some existing windows in office floors</td>
</tr>
<tr>
<td>retrofit)</td>
<td>facing southeast in the morning hours</td>
</tr>
<tr>
<td>Day lighting (Tune up/minor</td>
<td>The existing Visible transmittance of double glazed windows which are at external 47%</td>
</tr>
<tr>
<td>retrofit)</td>
<td>and internal 88% is optimized by controlling existing mid pane blinds of windows</td>
</tr>
</tbody>
</table>

Table 1. Non-design interventions in retrofitting scenario in accordance with target benchmark of environmental performance

5.2. Technological interventions
Preliminary analysis of building characteristics and climate has led to the proposal for a number of modifications to the initial design. DesignBuilder simulation provides evidence confirming the external envelope as the main contributor of environmental loads- EL- (Fig 2B). Therefore, interventions are identified to the building design and engineering systems to reduce ELs involving all paradigms in the proposed methodology (Hyde et al 2009).

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Literature/Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARADIGM ONE</td>
<td>Thermal insulation to the internal surface of external walls on the northeast and southwest facades</td>
</tr>
<tr>
<td>Improvement of the U-value of envelope (major retrofit)</td>
<td>Integration of an additional 100mm thick high mass wall with a 50mm cavity created inside the insulation forming a double skin wall to the northeast and southwest Night ventilation for thermal mass cooling</td>
</tr>
<tr>
<td>Double skin wall with night ventilation (major retrofit)</td>
<td>Extension of the glazing downward in the exterior wall facing southeast and northwest Existing ratio 40 percent – proposed ratio 65 percent. New windows to staircase/lift lobby and toilets</td>
</tr>
<tr>
<td>Increase of glazing ratio for daylight (major retrofit)</td>
<td>Shifting of new glazed envelope within bays on the southeast and northwest inward creating full height shading on windows to prevent heat gain in summer</td>
</tr>
<tr>
<td>Shading for the glazed envelope</td>
<td>Integration of wide flat sensor operated air plenums under the glazed envelope formed by fixing thin concrete plates 300mm off the floor slabs</td>
</tr>
<tr>
<td>Controlled ventilation (major retrofit)</td>
<td>Daylight plenum in the central areas of the new double skin wall facing northeast and southwest orientations</td>
</tr>
<tr>
<td>Daylight tube (major retrofit)</td>
<td>Improvement of the air distribution system with air-to-mass heat removal system</td>
</tr>
<tr>
<td>PARADIGM TWO</td>
<td>Use of high-efficiency LED lamps with electronic ballast and daylight compensation Use of task lighting</td>
</tr>
<tr>
<td>High mass ceiling with extractor ducts</td>
<td>Provision of separately switched working, service and other circulation zones for each floor. Use of tenancy controlled lighting and time scheduled controls</td>
</tr>
<tr>
<td>PARADIGM FOUR</td>
<td>Use of heat recovery of the return air and Recovery of the waste heat from the plants Possible replacement of existing system with chilled water system</td>
</tr>
<tr>
<td>Synergies between passive and active systems</td>
<td>High thermal mass ceilings with potential for stack effect with mechanical systems</td>
</tr>
</tbody>
</table>

Table 2: Design based technological interventions for retrofitting in line with standards in Building Code Australia
6. TESTING OF RETROFIT SOLUTION

Use of computer based analytical tools
Energy efficiency gains from retrofit interventions were modelled and calculated by applying best and standard practice values in available benchmarking protocols. The benchmarking protocol identified was BCA (Building Code Australia). The assessment was performed on following two directions for a typical summer week (10th – 16th February) and the total summer in 2009;

A. Total performance target with selected non-technical interventions i.e. increase of set point temperature from 23 to 24 Degrees C, 0.5 infiltration from 1.0, BCA operational profiles and scheduled window blinds operation

B. Cumulative performance target with technological interventions in BCA standards i.e. insulation to external envelope, light sensors, blinds operation with solar sensors,

![Mind map for simulation of energy reduction targets through the integration of two solution sets](image)

Figure 3. Mind map for simulation of energy reduction targets through the integration of two solution sets (few of non-technical and few of technological interventions)

7. RESULTS AND DISCUSSION

Results of the “Advanced Renovation Research Project” of 160, Ann Street in Brisbane, illustrate significant performance benefits from non-technical and technological bioclimatic retrofit interventions. In respect of environmental performance standards in existing buildings, AGBR’s National Australian Built Environment Rating system (NABERS), achieving efficiencies in controlling heat gain (Fig.4) which could contribute to energy performance towards a higher NABERS rating has become evident for this building.

![Heat gain reduction in KW due to non-technical strategies](image)

Figure 4. Left: Heat gain reduction in KW due to non-technical strategies. Right: percentage reduction of heat development inside the building during summer typical week February 10th - 16th 2009

A 1 deg C increase in cooling set-point temperature results an approximately 9% decrease in total summer cooling energy load. A 3 hour reduction of HVAC operational schedule (from a fraction of 100% to 25%, from 21.00hrs to 18.00hrs) results approximately 5% decrease in total summer cooling energy load in 2009.

Integration of technological interventions for BCA specifications, such as an envelope with expandable polystyrene insulation, 50mm cavity and an additional inner brick layer producing a U value of 0.565 (R=1.8) of the external opaque envelope, efficient lighting and solar blinds operation by light sensors contributed to significant reductions in heat gain inside the building (Fig.5).
A number of performance improvements involving non-technical and technological interventions were tested. The impact of these interventions on the heat gain, thermal performance and energy reduction targets are being investigated for the total summer period and for the year. For example, interim results show that in the context of 2009 climatic behaviour, the improvement of the U value of the building’s external envelope to 0.565 will contribute to a reduction of annual energy use from 2,087,787 KW h to 1,508,857 KWh. Consequently, the projected energy footprint is 95 KWh/m²/annum which is a 27.7% saving. Accordingly, the building achieves a 4 Star NABERS rating. The greenhouse gas emission reduction contributes to the national emission reduction targets.

More work is in progress to produce a road map for achieving a zero emission building operation and the results will be published elsewhere. The detailed cost benefits of these measures have yet to be carried out in detail. However, allowing a Premium or Grade A office tower in Brisbane CBD to decay to a Grade B or C results in the rental income cost benefits of these measures have yet to be carried out in detail. However, allowing a Premium or Grade A office tower in Brisbane CBD to decay to a Grade B or C results in the rental income

CONCLUSION

The objectives of the research were to investigate the environmental performance of 160, Ann Street and improve its NABERS rating through retrofit interventions to operation and design of the building. The building was evaluated as a critical case and findings of the research contributed to generalise/evaluate a methodology for advanced renovation of commercial high rise buildings with the intent of improving its energy performance. The final outcome of this research aims to predict the energy efficiency of the renovated property and will be published elsewhere. Evidence demonstrated by the performance gains, presentation of the research process and results will be shared among a wider group of researchers and building professionals. This paper is presented as an interim research outcome and limited to the property’s environmental sustainability in respect to energy use in summers.

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Figure 5. Left: Heat gain reduction in KW due to selected technological interventions. Right: Percentage reduction of heat reduction inside the building during a summer typical week February 10-16, 2009


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