Towards a methodology for retrofitting commercial buildings using bioclimatic principles

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ABSTRACT: The paper argues that in order to achieve effective greenhouse gas mitigation targets and adoption of existing commercial buildings to climate change effects, a methodology for retrofitting is needed, largely based on bioclimatic design as it promotes low energy building operations. An initial work is presented on implementing this approach involving four types of activity:

1. Climate analysis and climate change effects
2. Trend analysis of energy and water consumption of existing buildings
3. Integrating retrofit strategies with the building embracing technical and behavioural parameters
4. Modelling efficiency and effectiveness of strategies

The use of existing tools for climate analysis, climate change predictions, strategising and testing becomes an essential stage in the methodology. Trend analysis focuses on the synergies between behavioural and technological parameters in respect to energy and water, for which ongoing engagement with the owners and occupants in an action research approach where retrofit interventions are matched against outcomes is needed. This will lead to identify causes and effects with energy and water use over time. Outlining the process of retrofit solutions and testing efficiency of situations where solutions are applied are discussed as crucial stages. Opportunities for implementing a successful retrofit methodology with the use of case studies are being explored in the research.

Conference theme: Urban

Keywords: Bioclimatic design, evidence base policy, energy conservation, retrofitting

INTRODUCTION

The International Panel on Climate Change (IPCC) recently reported that buildings offer the largest share of cost effective opportunities for Green House Gas (GHG) mitigation among industry sectors. Achieving a lower carbon future will require very significant efforts to enhance programmes and policies for energy efficiency in buildings well beyond what is happening today (IPCC 2007 p306).

According to the 2007 IPCC Report, it is clear that buildings present the biggest potential to decrease the CO₂ emissions considering energy efficiency strategies that must take place. These actions focused on a technical approach related to the architectural and engineering fields. However, several technical and engineering improvements for new and existing buildings are mandatory and four major groups can be classified as the main measures into the building scale: (1) reduce energy for heating, cooling and lighting loads; (2) improve use of insulation, thermal mass of the building; (3) increase the efficiency of appliances, HVAC systems and (4) increase the efficiency of lighting systems.

Major measures indicated in this document are mainly focused on new construction rather than existing buildings. It recommends that, more efficient equipments for heating and cooling, advanced or “intelligent” building’ envelopes as well as more effective insulation design need to be effectively applied into newly constructed buildings. Furthermore occupant behaviour, culture and consumer choice and use of technologies are also major determinants of energy use in buildings and play a fundamental role in determining CO₂ emissions. There is high agreement but limited evidence that the potential reduction through non-technological options is important but rarely assessed. Also the potential leverage of policies over these determinants - occupancy behaviour, culture, consumer choice and use of technology- is poorly understood’ (IPCC 2007 Chapter 6 Ibid).

A response to these issues is to develop a methodology for integrating these determinants in an ‘action research’ approach for retrofitting existing buildings (French and Bell 1973). Action research is a methodology based on ‘intervention and reflection’ where specific strategies are proposed, implemented and consequences tested. The paper aims to present initial work examining the potential for the interplay of these determinants for environmental efficiency in existing commercial buildings. In particular the focus will be on the technologies that are commonly associated with bioclimatic design namely the increased use of natural light, ventilation as well as solar energy and the reduction of unwanted environmental influences such as solar overheating. From this, an “outline” for a methodology for implementing bioclimatic retrofit for existing commercial buildings in warm climates is proposed.
The first part of the paper presents the context to renovations in terms of emerging ‘futures’, namely climate change predictions and the potential for technological and behavioural change to provide the necessary mitigation and adaptive conditions necessary to address GHG emissions reductions and explains the approach to retrofitting. A phased methodology is suggested using a combination of activities- climate analysis, building monitoring, computer simulation and studies of owner and occupant behaviour. The second part provides initial results involving case studies located in the subtropical climate of Queensland and temperate climate of Sydney. These buildings are used to represent critical cases for the examination of these issues. Rather that examine a wide range of types of buildings, it is argued a critical case or cases can be defined which have strategic importance in relation to the general problem under investigation and that generalizations to other cases can be made from this example.

PART 1 TOWARDS A RETROFIT METHODOLOGY

1.1 Approach
The initial work of the research highlights the climate change effects as important determinants of energy demand in buildings. This suggests that global warming is likely to have a negative effect on existing commercial buildings because of a large portion of such buildings were not designed to address this. Further, important role of system performance and occupant/owner behaviour on system management and comfort expectations on energy demand is evident. These relationships are considered in bioclimatic design (Olgyay. V, 1963) which involves with the building scale to promote benign built environments integrated with the climate for indoor comfort. Therefore, an examination of existing buildings in relation to a methodology that can take account of these areas will be useful in quantifying the actual behaviour of them and, then to suggest retrofit solutions and explore their potential benefits. Four primary activities are proposed in two areas:

Diagnosis for retrofit
1. Climate influences and climate change effects.
2. Trend and system analysis of energy and water consumption of existing buildings.

Prediction of retrofit
3. Apply retrofit strategies.
4. Test efficiency and effectiveness of strategies.

This approach is examined through the use of case studies, which include studies of the stages of diagnosis in order to be able to focus more accurately on stages of prediction. Case studies are used to explore a number of issues in respect to these four activities of the proposed methodology.

1.2 Diagnosis- Climate influences and climate change
Increasing evidence of climate change shows an increase of outdoor temperatures in warm climates suggesting an increase in the environmental loads into the buildings. Failure to address such negative impacts on existing buildings through appropriate design interventions, and the degrading of active systems that already exist in buildings can lead to increase in energy use. Further, it is evident that much of the existing building stock perform very inefficiently in terms of energy (Wilkinson and Reed, 2005) and therefore, a critical analysis of climatic behaviours of macro, meso and microclimates and their negative effects on the design of buildings in order to assess the performance of buildings is required. CC World Weather Gen Tool from the University of Southampton can model such predicted climate change effects on local macro climate patterns. These predictions are based on HadCM3 (Hadley Centre coupled model version (3) and IPCC TAR (Third assessment report of IPCC) on climate change scenario data.

1.3 Diagnosis- Trend analysis of energy and water usage
Existing buildings can become obsolete due to many reasons including inefficiency of indoor climate control measures, services and systems as a result of increase in environmental and internal loads called captive energy. In particular, unprotected building envelopes with large areas of glass provide potential overheating in which air-conditioning results in more energy use consideration of both environmental loads and internal loads are important. Table 1 shows levels of energy consumption due to design and heat load control type of office buildings. (EU2009)

<table>
<thead>
<tr>
<th>Office Type 1</th>
<th>air-conditioned standard, with heating, ventilation and building related electricity consumption, electricity consumption/m² of staff:</th>
</tr>
</thead>
<tbody>
<tr>
<td>low consumption: less than 110 kWh/m²/year (good practice=76)</td>
<td></td>
</tr>
<tr>
<td>average consumption: 110-130 kWh/m²/year (typical= 117)</td>
<td></td>
</tr>
<tr>
<td>high consumption: more than 130 kWh/m²/year (typical is already high)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Office Type 2</th>
<th>naturally ventilated open-plan, without heating, ventilation and building related electricity consumption (e.g. elevators), electricity consumption/m² of staff:</th>
</tr>
</thead>
<tbody>
<tr>
<td>low consumption: less than 70 kWh/m²/year (good practice=49)</td>
<td></td>
</tr>
<tr>
<td>average consumption: 70-80 kWh/m²/year (typical=75)</td>
<td></td>
</tr>
<tr>
<td>high consumption: more than 80 kWh/m²/year (typical is already high)</td>
<td></td>
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</tbody>
</table>
Environmental loads- ambient energy and architectural design
The increased temperatures due to climate change found in the warm climate like Brisbane will create additional “environmental loads” on buildings increasing the cooling load. Environmental loads such as solar radiation typically contribute 34 per cent of the cooling loads, transmission of 6 per cent and outside air 15 per cent (Parlour 1997: 79). Solar radiation is the largest component and has important implications with regard to the definition of passive zones, which quantify the potential to use natural light and ventilation without heat gain from outside. Architectural design of the building provides a proportion of passive to non-passive zones, which in turn provides an estimate to introduce passive and low energy design strategies. Passive zones with proper defensive measures against unwanted solar gain need much less effort and thus energy than non-passive zones in controlling indoor climate. Therefore, with the increasing external temperatures due to climate change, increasing and optimizing passive zones through architectural design can contribute to address high energy demands associated with the influx of increased heat load.

Internal loads- captive energy and heat load controls
Studies looking at office types point to new benchmarks for energy use that disaggregate according to the services and heat loads created by captive energy from the use of equipment in the building. The results in the Table 1 are from the EU Intelligent Energy project, ‘Boosting efficiency in electricity use in 8 European regions’, which shows diversity of energy usage due to design and heat load control methods (EU 2009 http://www.oekoenergie-cluster.at).

The naturally ventilated open-plan typology refers to purpose-built with some cellular space within the building with size ranging from 500m² to 4,000 m². The air-conditioned standard typology refers to purpose-built buildings with an average size of 2,000 m² to 8,000 m². The concern is the increase in what is called captive electricity.

Occupant behaviour
The influence of building occupant behaviour on the energy consumption of buildings is visible, and understanding this is essential for evaluating and predicting energy use in buildings (Steemers and Yun, 2009). The occupant behaviour on the choices made about required comfort standards, control mechanisms involved with heating and cooling systems, and selection of appliances is a major determinant of energy consumption. Further, changes in occupant behaviour in the context of retrofitting office buildings can become a significant concern in the design and implementation of retrofit strategies. More research in this area is in progress. The use of energy in this way is due to many reasons. The non-technical reasons are four-fold:

1. Increased comfort standards- the use of tight comfort parameters. Expanding comfort parameters is seen as important part of controlling energy use. Currently the Adaptive Model of thermal comfort could be applied to air conditioned buildings with the view of reducing energy consumption in retrofitting (de Dear, R 2009).

2. Limitations in facilities management. Occupant behaviour is seen as a method of reducing operational energy use through better facilities management (Shiel 2008). Retrofitting with improved technological needs and change in behaviour of fund managers and owners provide the necessary investment capital for retrofit. Thus the involvement of owners, tenants and occupants in operation, management and training is vital. Engaging owners, tenant and occupants in the operation and management of commercial owner/building manager behaviours are (ARUP 2008) essential to have functional operation of systems. Opportunities for refurbishment may be presented when tenants change: when building systems need updating; when smart metering is installed allowing more accurate measurement of energy; and when a similar refurbishment project inspires an upgrade (EIE 2007).

3. Selection of appliances within the building to reduce captive load. The rises of IT equipments (computers, printers, large computer room) are linked with large stand-by consumption. Also, too much lighting with too high luminance compared to the needs, and lack of optimization of the natural light, increases the captive load of lighting appliances. Thus the selection and use of appropriate appliances are necessary to limit the consequences of far too high installed power of appliances. (EU 2009 http://www.oekoenergie-cluster.at).

4. Role of design- linking concept with operations. When behavioural and technical issues of buildings are beyond active systems, architect’s design plays a major role. Hence passive design strategies, which are already known for energy saving potential, can become more significant in indoor environment control. On technical perspective when architect’s designs are extremely dependent on mechanical systems and occupant’s habitability (including thermal comfort issues), these buildings fall within the domains of engineers. Therefore, it necessitates a change to “passive” design approach from an “active” design approach. When designers are making decisions about their projects, they need to apply passive strategies with an “active” design process where the bioclimatic approach can take place. However, more sophisticated processes require simulation and prediction skills etc. Architects must be as fluent in scientific thinking as they are in humanistic thinking if they wish to create buildings whose sustainable features are an integral part of the design (Hyde 2008). In other words, designers cannot rely anymore on technical solutions in order to solve energy conservation issues. It is necessary to go further and to encourage more ‘active’ behaviours of occupants within a holistic approach.

1.4 Prediction- Framework for applying retrofit strategies
Understanding climate change effects on buildings, and trends and systems of environmental performance will enable to identify retrofit interventions for the improvements of existing performance of buildings. Initial work of the research has identified four main paradigms for retrofitting.
• Paradigm 1 *External passive systems* – use of building external envelope as the third skin between human and climate in order to reduce solar gain and promote ventilation in summer, capture or retain heat gain winter and promote daylight in both seasons (Drake, S).

• Paradigm 2 *Internal passive systems* – use of building form/sectional characteristics and planning of spaces to support the paradigm 1, capturing optimum ventilation, day lighting and manipulating/controlling heat capture from environmental and internal loads.

• Paradigm 3 *Active systems* – efficiency of plant and equipment, reduction of air conditioned space.

• Paradigm 4 *Synergies between active and passive systems* – use of mixed mode where envelope/façade and air-conditioning system can be linked with human interaction for efficient control of systems.

1.5 Prediction- Test efficiency and effectiveness of strategies

Case studies

A case study approach is used to demonstrate testing of the design paradigms. The case study approach is used primarily as a result of dissatisfaction studies with large ample sizes and statistic analysis methods which can obscure rather that illuminate the interrelation of the variable examined (http://www.jstor.org/pss/248684). It is argued that the field requires exemplars in this area hence the methodology defined here begins to address these issues (http://qix.sagepub.com/cgi/content/abstract/12/2/219.)

Computer Simulation Modelling

Two computer based simulation tools, LTV (Hyde and Pedrini 2001, 2002) and Design Builder (http://www.designbuilder.co.uk) are used. The advantage of using LTV is that it can be used to develop results quickly although it only examines a limited number of variables. LTV is useful for examining variables which are organised in the planning of the buildings. These parameters include: plan depth (shallow or deep plan), orientation (north south east or west), Window to wall ratio (opaque versus transparent elements), Shading (full to shading to no shading) and Passive zoning (natural ventilation and daylight versus active zones, artificial versus natural ventilation).

Fig 3 – left- shows a change in the energy consumption with window to wall ratio due to window height.

This tool developed for the pre-design and sketch design stage gives information concerning energy and therefore CO₂ impacts. The aim of the modelling is to use ‘critical cases’ to test the effects of the four main retrofit paradigms. The project has identified a number of critical cases, which contain the main dimensions to the topic in the field of investigation. At present two buildings are under investigation as critical cases- a low rise office, which has curtain wall systems with air conditioning that requires an upgrade in energy use. The other is an office building in Sydney, which provides useful information on energy and water trends related to behaviour and technological changes.

PART 2 BUILDING CASE STUDIES

The research work is still at an initial stage of development with only partial data sets on the case studies. However there is enough information to frame these studies to frame a discussion concerning the proposed methodology.

2.1 Case study – Brisbane

Current climate condition and strategies

Critical Case One, which is a low rise office building found in Brisbane, Southeast Queensland, for which four main climate responsive strategies are found in order to extend the comfort zone using the passive design features of buildings. These are passive solar heating, cross ventilation, evaporative cooling and thermal mass. These strategies are often combined to create passive building systems, for example high thermal mass and heat sink is linked with passive solar for winter heating and with cross ventilation at night for summer cooling. Fig 1 shows how thermal mass combined with ventilation and passive solar can extend the comfort zone in summer and winter to accommodate mean maximums and minimums.
Figure 1: Psychrometric chart for South East Queensland showing climate responsive strategies of cross ventilation and passive solar heating (left) as well as thermal mass, evaporative cooling (right).

Climate change effects
The present day weather file for Brisbane representing RMY (Australia Representative Meteorological Years 1967 to 2004) data for 2006 is simulated. The results indicate an increase in the mean maximum temperature over the years to come and associate increase in the number of hours of extreme temperatures in a year begin to provide some confronting evidence of the need to reconsider bioclimatic strategies for warm climates as shown in Table 2. Current assumptions concerning a particular climate and effectiveness of particular bioclimatic strategies are now changing with this type of climate changes. The question that now arises is how climate change will affect the current building stock particularly in warm climates?

Table 2: Brisbane, Australia. Increase in the number of hours per year for temperatures over 28 degrees C

<table>
<thead>
<tr>
<th>Year</th>
<th>T&gt;28&lt;30</th>
<th>T&gt;30&lt;32</th>
<th>T&gt;32&lt;34</th>
<th>T&gt;34&lt;36</th>
<th>T&gt;36&lt;38</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>423</td>
<td>119</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2050</td>
<td>558</td>
<td>243</td>
<td>56</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2080</td>
<td>791</td>
<td>470</td>
<td>200</td>
<td>46</td>
<td>2</td>
</tr>
</tbody>
</table>

For example, climate responsive strategies are limited in their effectiveness for cooling to about 30 degrees C at high humidity. As Fig 1 shows the effects of thermal mass strategies and evaporative cooling for indoor comfort are possible. However, as seen from the climate change effects in Table 2, mean temperatures above 30 degrees for nearly 30 days per year would be expected (BOM). Hence additional strategies are needed and with extreme temperatures in summer the effectiveness of these strategies is questioned. Furthermore, the effects of climate change on the diurnal range of temperature are being examined to assist with determining the limitations more fully.

Critical Case One in Brisbane (Fig 2) is investigated in this area of concern. Initial testing of the low-rise case involves the use of LTV to give some indication of the likely energy consumption. Typical floors are used and a base case developed. Initial work of this case has involved testing the effects of retrofitting proposal for Paradigms 1 and 2. In this case, the benefits of renovation have influenced not only the use of bioclimatic systems but also the use of additional retail space. This provided a buffer between the office space and a major road to the front of the building. The renovation shows that the reduction of energy for cooling from the westerly zone (Fig 3 right). Not shown in the LTV is the associated effects of the solar chimney which removes heat in summer avoiding additional loading. Additional work will use LTV to develop further the use of passive strategies, reduction of air conditioned space. LTV will give an initial set of optimum strategies for further testing using Design Builder.
Figure 3: left - LTV is used to compare energy consumptions due to window to wall ratio in a sample, right - A comparison of predicted annual energy consumption in kW/m² of existing design parameters with retrofit solutions in Critical Case One

2.2 Case study- Sydney

Trend and systems analysis of energy and water consumption

The work on trend and systems analysis over time is useful as it begins to show the dynamic nature of energy use and influence of technological improvement regarding the use of building retrofit. Developers argue that demonstrating the reduction of energy use in buildings improves asset appreciation and assists with attracting tenants. Work shown in Fig 4 gives a trend analysis of energy consumption in a building in Sydney. Understanding the behavioural aspects of this in terms of cause and effect is needed in order to identify retrofit strategies. In his case study changes in the trend lines for energy (light grey) and water (dark grey) are shown. These are mapped against technical and behavioural interventions and costs shown in the vertical lines and key below. This kind of study is useful to compare to a base case (dotted lines) to give benchmarking performance. This kind of performance measures allows owners and users to verify to continually improve their buildings which is a key environmental principle.

Figure 4: Trend and Systems Analysis with technological interventions mapped against energy and water use with associated economic considerations. Additional information is needed to relate causes and effects to the trends seen here in particular effects of behaviour

3. DISCUSSION

Further work on testing of new solutions for renovation is possible using the methodology. A level of validity with the results is achievable given the ability to triangulate three data sets; data on climate and building attributes, monitored data from building operations and with data from simulation using LTV and Design Builder tools.
More over there is possibility to utilise new software tools for predicting climate change which seem to give the ability to assist with examining the influence on bioclimatic strategies. Evidence from some of the research so far seems to indicate the problems with the building envelope with regard to the yearly pattern of solar radiation. Trend analysis shown in Figure 4 shows the sensitivity of buildings to summer and winter conditions with peaks in both seasons, which demonstrates poorly functioning envelopes. The effects of this will only be exacerbated with the temperature increase of 2 degrees and extreme temperature events as shown in Table 2. This seems to demonstrate increasing need to have support from Paradigm 1, currently examined in this research work, that of using bioclimatic strategies to articulate the envelope to address climate effects and thus improve energy efficiency.

There is evidence that utilising Paradigm 3, Active systems - efficiency of plant and equipment to create air conditioned space more efficiently, is likely to be ineffective given the rising demand for captive energy and associated waste within the building. Evidence from the renovation of the low rise office seem to offer some measure of effectiveness of building design, using a solar chimney to remove waste heat and also to increase shading in this case to the west to remove heat load from solar radiation. Hence both the solar loads and internal heat loads can be addressed through passive means rather than through additional cooling using fossil fuel energy.

Further work is needed to examine the behavioural consequences of these strategies. The methodology (Fig 5) is yet to fully address these issues. The current paradigms offer little in terms of the nuances of human interaction with the technical systems, hence it may be possible to utilise an ‘adaptive’ model of thermal comfort and ‘active’ model of behaviour with retrofitting using Paradigm 4 Synergies between active and passive systems - use of mixed mode where façade and air-conditioning system can be linked.

Clearly the Paradigm 2, Internal passive systems - optimizes day lighting, reduces cooling/heating loads and effects of waste heat from captive energy use. But the effects of climate change are going to minimise the effects of these systems, therefore additional strategies need to be considered. In warm climates such as Brisbane the days of temperatures over 30 degrees C will increase and the opportunities for natural cooling will be reduced. Seasonal change will mean buildings will have distinctly different modes of operation both in terms of technical and human systems if greenhouse gas emissions are to be mitigated.

4. CONCLUSION

The paper presents and discusses an emerging methodology for implementing bioclimatic retrofit to exiting office buildings. These buildings may be characterised by passive occupants, increasing captive energy use for equipment, poor envelopes/facades, obsolete services and high-energy consumption. Energy consumption is increasing on a yearly basis in time with increasing external temperature.

Addressing this trend requires breaking the cycle and hence a methodology is proposed to set in place measures both in the design and operations. Four paradigms for retrofit are examined and discussed regarding their relative effectiveness. It is argued that synergies between active and passive systems through the use of mixed mode where envelope/façade and air-conditioning system can be linked with active behaviour. Further work using simulation and monitoring of operation performance will be examined.

5. ACKNOWLEDGEMENT

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