STRATEGIES FOR PRACTICAL GREENHOUSE GAS REDUCTIONS IN THE EXISTING BUILDING STOCK

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ABSTRACT

The Stern Report found that Climate Change is the world's greatest market failure, and the United Nations concluded it is likely to be the most significant environmental challenge of our time. This paper aims to illustrate building Greenhouse Gas (GHG) and energy trends, and to provide practical strategies and best practice examples in international low- and high-rise building refurbishments to lower GHG emissions, energy use and operating costs, across building types and Australian Climate Zones. These can be adopted by policy-makers, owners, investors and occupiers. It also aims to provide examples of government policies and important stakeholder behaviour to reduce GHGs, and evaluates one recent project for strategies that proved successful and those that could be improved. The method used was to review international strategies that lower building GHG emissions in countries with more advanced building regulations than Australia, and to discover affordable and effective strategies from associations that publicise case studies. This paper shows that the operational phase of buildings is a significant contributor to global GHG emissions; that Passive building refurbishments are current best practice strategies; and that occupant behaviour is another surprisingly significant contributor to GHG emissions. The paper forms part of the author's higher research degree literature review.

KEYWORDS

greenhouse gases, existing buildings, refurbishment strategies, energy efficiency

1. INTRODUCTION

The Stern Report found that Climate Change is the world's greatest market failure (Stern 2006), and the United Nations concluded it is likely to be the most significant environmental challenge of our time (UNEP-1 2007).

The Building Sector uses between 30–40% of global energy consumption (UNEP-2 2007), and for some developed nations such as Australia, the source of that energy is largely from fossil fuels producing high levels of the Greenhouse Gas (GHG) carbon dioxide (CO_2).

There are great opportunities to lower cost-effectively the GHG emissions of existing buildings because:

- around 80% of a building's energy consumption occurs during the operational phase (WBCSD-1 2007),
- refurbishments prolong the lifetime of buildings, reducing any demolition energy, recycling the envelope and structure and reducing the embodied energy of any new materials,
- GHG lowering strategies could be done at the same time as repairs and refurbishments that are needed on commercial and residential *tenant churn* or on the regular maintenance schedules of fitouts and systems,
- as energy prices escalate, operating costs are becoming problematic (Lehmann 2007), and these will increase with the introduction of a Carbon Emissions Trading Scheme,
- there are a large number of older buildings that will endure in the existing stock, and which do not comply with the recent mandatory energy performance provisions of the Building Code of Australia, and
- there are regions with more advanced building energy performance that can provide good models for Australia eg. in the EU and the Americas, particularly in Germany, Austria, Canada and California.

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This paper forms part of the author's higher research degree literature review, which is expected to be completed in the first quarter of 2009, to assess strategies that lower building GHG emissions.

2. AIMS

This paper aims to illustrate building Greenhouse Gas (GHG) and energy trends, and to provide practical strategies and best practice examples in international low- and high-rise building refurbishments to lower GHG emissions, energy use and operating costs, across building types and Australian Climate Zones. These can be adopted by policy-makers, owners, investors and occupiers.

It also aims to provide examples of government policies and important stakeholder behaviour to reduce GHGs, and evaluates one recent project for strategies that proved successful and those that could be improved.

3. METHOD

The method used was to review international strategies that lower building GHG emissions in countries with more advanced building regulations than Australia, and to discover affordable and effective strategies from associations that publicise case studies.

Buildings are classified according to their major activity, eg. residential and commercial, and commercial buildings can be further subdivided into offices, retail etc. It also uses the Climate Zones of the Building Code of Australia (BCA) (YHTM 2008) and the Koppen climate classification to match Australia's climates for its most populous cities with those of international buildings. Monetary values are converted to Australian dollars using the exchange rate for the last business day in June for the relevant year according to the historical data tables of the Reserve Bank of Australia (RBA 2008).

Best practice strategies to lower GHG emissions are an ever-improving set of methods, and those chosen in this paper were obtained from more advanced countries than Australia, and from case studies published by associations such as the US Green Building Council (LEED 2007) that classifies buildings with good environmental characteristics.

Practical best practice GHG reduction strategies are those that are affordable and that use local materials, products, services and that suit the objectives of the project and the local level of technology.

4. RESULTS

Greenhouse gases (GHGs) retain atmospheric heat by absorbing and transmitting infrared radiation. They occur naturally, and from human activities, and include water vapour, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (WBCSD-2 2007).

4.1 The Building Lifecycle

GHGs are related to a building's energy consumption, any production of fluorocarbons from services, and the occupants' goods, food and services purchased and travel and waste produced. The GHGs emitted when energy is used over a building's lifetime are made up of (UNEP-2 2007):

- *embodied* energy used in production of the raw materials,
- *grey* energy in transporting raw materials,
- *induced* energy used during construction,
- *operational* energy, and
- *demolition* energy.

Building refurbishments are not included as a separate phase in this lifecycle analysis, but combine the first three phases, and in developed nations, materials with the highest embodied energy are often the cheapest, strongest, fastest and easiest to install (eg. steel, concrete, aluminium, plastics). In addition, raw materials are being transported larger distances and there is evolving mechanisation of construction techniques.

The significant GHG emissions related to the *operation* phase of a building vary according to

- the *energy consumption* due to the *building design options* including building orientation, insulation, window area, thermal mass, and the selection and optimisation, configuration and efficiency of *services* such as heating, ventilation and air cooling (HVAC), hot water, lighting, appliances, waste and recycling options,
- the *behaviour* of the building occupants excluding that due to interacting with the building

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services, eg. their transport modes, and consumption and disposal of different types and quantities of goods and services, including food (ACF 2007), and
- the type of *energy sources* eg. fossil fuel, biomass or renewable.

4.2 World Building Energy Trends

Figure 1 shows the annual 2003 primary energy (energy from primary fuels before transformation into electricity etc.) in terawatt-hours (TWh) for commercial and residential buildings across major regions. The GHG emissions from the building primary energy consumption depend on the fuels used on site, and the fuel mix used for any building electricity.

4.3 Trends in Australia

Australia is one of the world's largest GHG emitters per person, at around 28 tonnes (t) CO_2-e/yr in 2006 (DCC-2 2008). The 28t CO_2-e/yr is distributed with 20% emitted for household energy (electricity, gas etc.); 10% for transport; 28% food related; 12% for construction and renovations; and 29% for other goods and services (ACF 2007). So occupant behaviour is very important in reducing GHGs.

Mandatory building energy performance measures began in Victoria and the ACT in the 1990s and were only recently introduced across Australia into the BCA for housing in 2003, for units and apartments in 2005 and for commercial buildings in 2006.

Pears (Pears 1998) found that the Australian housing stock was not up to the standard of the EU and parts of US with regard to insulation levels and heating technologies. He also found that in Australia building longevity is decreasing; that housing is increasing in size while the number of occupants is decreasing; that the central heating and cooling is increasing; that more and larger appliances such as fridges and TVs are being purchased; that there is a substantial rental base; and as people age, they are spending more time at home thereby emitting more GHGs.

There is also a trend towards more Healthcare & Aged Care facilities to cater for the ageing population, and these are energy and GHG intensive buildings.

In considering which abatement opportunities were applicable to the building sector in Australia, and those that could be investment *net positive* over the lifetime of the abatement, McKinsey (McKinsey 2008) states

> Significant opportunities include improving *commercial air handling, air conditioning* and *residential water-heating systems*. Australia's relatively low level of insulation creates significant opportunities for increased energy efficiency in residential and commercial buildings. Other major areas of opportunities include reducing energy consumption through improvements in *lighting* and mandating that appliances have energy-efficiency *stand-by features*. (McKinsey 2008:13), with emphasis by the Author.

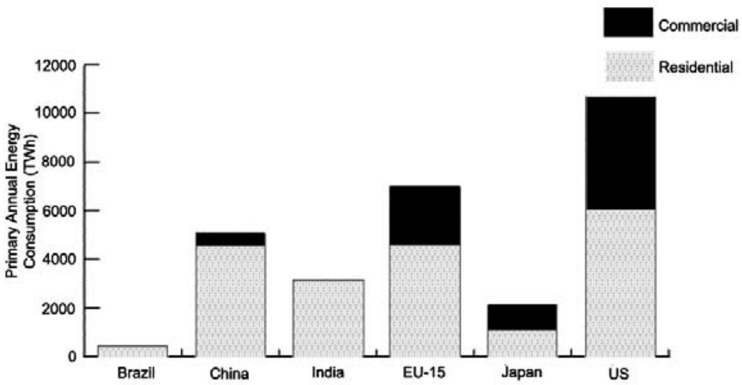

FIGURE 1. Annual Building Primary Energy Consumption by Region, 2003.

Source: (WBCSD-1 2007)

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4.4 Fuel Sources

For the building sector's primary energy, the US and the EU use more of the higher-emitting fossil fuel sources such as coal, oil and gas for electricity, heating and cooling whereas India and China rely mainly on biomass (WEC 2007).

In 2002, the countries with the largest building sector GHG emissions, in Megatonnes of Carbon Dioxide equivalent (Mt CO_2-e), were the US with 2,000; the EU-25 with 1,250; China with 550; India in 5th place with 200; and Australia in 15th place with around 100 (WRI 2005). So although China and India have large building primary energy consumptions, their GHG emissions are not that high, and they are quite low in terms of per capita, whereas Australia was in third place on a per capita basis after the US and Canada in 2006 (WRI 2005).

This is because Australia, like the US, has a high reliance on fossil fuels for electricity. Table 1 shows the state emission factors ie. the equivalent amount of CO_2 produced in kilograms per kiloWatt-hour of electricity produced, using a full cycle analysis, which includes transport and transmission emissions (DCC-1 2008). This shows that the trend of GHG emissions depends on the fuel mix used across the state power station generators eg. mainly hydro-electricity in Tasmania and brown coal in Victoria.

The World Energy Council identified electricity generation as the most significant industry to lower GHG emissions and the one where government polices are instrumental (WEC 2007).

4.5 Building Types

Residential buildings use more energy than commercial ones, and over 90% of all building energy in developing nations (UNEP-2 2007), as also illustrated in Figure 1, but commercial buildings are being developed faster (WBCSD-1 2007).

Otto from WBCSD (WBCSD-3 2007) presents a graph of the intensity of energy per square metre against the total consumption of energy for different building types in the US, and highlights building types such as Food Service and Health Care which have high energy intensities but with a total average energy consumption less than that of all homes.

The same pattern could be assumed to hold in Australia, and this type of graph would be a useful tool to draw attention to building types of large energy intensity and of large total energy consumption, which may deserve particular refurbishment attention.

TABLE 1. Australian GHG Emission Factors for supplied electricity.

State	GHG Emission Factor (kg CO_2-e/kWh)
Tas	0.13
NT	0.79
SA	0.98
WA	0.98
Qld	1.04
NSW/ACT	1.06
Vic	1.31

4.6 Energy Consumption and Passive Buildings

Refurbishments of buildings can use similar approaches to new buildings (UNEP-2 2007) that are:

- high-energy—with standard materials that use more than 50% of the normal building consumption,
- low-energy—with standard materials that use less 50% of the normal building consumption,
- zero-energy—where the energy used annually is the same as that produced by the building, and
- energy-plus—where more energy is provided annually than they use.

The Passive building approach is considered best practice and cost-effective (UNEP-2 2007 and IPCC 2007), and it is a form of low-energy building that requires minimal energy for heating and cooling, and has the characteristics of:

- the envelope—highly insulated components eg. double glazing
- air-tightness—no air leakage through unsealed joints eg. rubber-sealed doors and windows
- ventilation—where a mechanical system can recover heat from exiting air to assist warming the entry air
- few thermal *bridges*—stop heat loss from poorly insulated areas eg. at windows, doors or balconies
- window size and type—minimize heat loss in winter and heat gain in summer

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Zero-energy and energy-plus buildings have some form of power generation and storage eg. batteries or grid-connection, and usually have Passive house characteristics (UNEP-2 2007).

4.7 Case Studies

The case studies in Table 2 are examples of best practice strategies to meet specific goals in a Temperate climate. There are two cases of low-rise refurbishment projects and two cases of high-rise projects, and the table has their descriptions and goals (eg. whether an energy-efficiency or comfort upgrade), costs of the refurbishment, the strategies that were applied to the envelope and to the services, and the results and references.

Refurbishments to the 55 units in Schransstraat used affordable strategies that saved 70% of their previous energy, and was such a great success that the housing organisation began refurbishing another larger set of buildings.

Half of the 24 units in Hoheloogstrasse were refurbished as energy-plus buildings with PV panels, and these strategies show how to reduce dramatically GHG emissions.

The 7 storey Zurich office had insulation and retractable awnings added to the exterior, which greatly improved its Passive cooling characteristics, and vents that allowed night purging. A new combined heat and power (CHP) plant, and heat recovery from the ventilation system together with the envelope update produced significant energy cost savings.

The last example was a refurbishment to the relatively new Environmental Protection Agency (EPA) headquarters in California that was not performing to the standard required, and so the affordable strategies implemented included mainly new services such as HVAC, PV panels and a heat exchanger, but also native plant additions for water reduction and significant occupant behaviour changes for transport and waste eg. cycling and worm-farm. In this case a Platinum level award was obtained (the highest level) and the simple payback period was less than 1 year.

4.8 Critical Review of a Refurbishment

In Raamsdonk, The Netherlands, 42 2-storey terrace dwellings, with additional attics and cellars were built in 1963–69, and refurbished by the Volksbelang Housing Association in 2000–2002 to update the buildings, and to improve comfort and their energy efficiency but by using only proven strategies (EIE 2007). The envelope strategies comprised:

- external insulation of roofs, cellars and walls
- highly-efficient window frames and triple glazing
- elimination of thermal bridges
- elimination of common chimneys

The services strategies carried out were:

- highly-efficient and improved boilers
- solar thermal heaters
- mechanical ventilation
- heat recovery of ventilation air

Both sets of strategies reduced the annual heating demand from 240kWh/m^2/year to 120kWh/m^2/year on average, which would have approximately halved the GHG emissions, for each 80m^2 unit at a cost of $70,000 (€39,900) each, which also included non-energy efficiency measures.

The external insulation and triple glazing are particularly effective strategies, however, additional strategies could have been deployed to further lower GHG emissions. Due to the large number of dwellings, strategies could have included

- a CHP system or a district heating system
- a renewable energy system such as a photovoltaic one
- improved lighting
- a building user manual, and
- the encouragement of a lower GHG lifestyle eg. maximising cycling, public transport and car pooling, recycling and green waste treatment with worm factories together with growing plants including food to filter the inside air, or even growing food outside on a community basis.

These strategies would have decreased the GHG emissions of the dwellings substantially, perhaps even becoming energy-plus buildings.

4.9 Strategies for Climates

Figure 2 shows the applicability of various UN energy-saving strategies that correlated with the Your Home guide for buildings in climates similar

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TABLE 2. Best practice case studies with energy and GHG reduction strategies.

Project & Climate	Description & Goal	Costs AUS$	Strategies		Results & Reference
			Envelope	Services	
Schransstraat, Vorselaar, Germany Built 1971, Refurbished 2003. Temperate	Low-rise units. 5 apartment blocks with 11 dwellings each of 3 storeys with cellar and attic. Wanted economically viable 70% energy savings and some comfort upgrades.	Architectural costs were \$4.3m (€2.5m), mechanical costs N/A.	1. External insulation 2. High performance double glazing 3. Glazed balconies to prevent cold bridges	1. Mechanical ventilation with heat recovery per unit 2. Solar hot water to heat 40% of hot water consumed.	Economical & long-lasting 70% energy savings refurbishment. Upgraded by Zonnige Kempen Social Housing with mainstream strategies. (Holopainen 2007)
Hoheloogstrasse Ludwigshafen, Germany Built 1960–62, Refurbished 2005. Temperate	Low-rise units. 24 dwellings each of 3 storeys with cellar and attic. Refurbished by the GAG Social Housing provider. Half of units to be energy-plus refurbishments.	Energy saving costs were \$26,400 (€16, 667) per apartment	1. Insulated roof, floor, facades 2. Triple-glazing 3. Thermal bridges removed (balconies separated) 4. Removed common chimneys	1. CHP with tank hot water storage 2. Photovoltaic (PV) system 3. Low temperature heating 4. Balanced ventilation with heat recovery	12 energy-plus units generate a net 35 kWh/m^2/year each, instead of using 250kWh/m^2/year previously. The other 12 units were renovated to EnEV Act 2002 standard. (EIE 2007)
Zurich, Switzerland. Built 1970, Refurbished 2001. Temperate	High-rise 7 storey office. Wanted energy-efficient upgrade when the building was expanded from 4,800m^2 to 6,200m^2.	N/A.	1. High quality external insulation 2. Retractable fabric awnings to South, East and West facades 3. Window vents for natural ventilation and night purging	1. CHP ceiling water for heating and cooling replaced oil boiler and air conditioner 2. New ventilation plant has heat recovery 3. More efficient and redesigned lighting	The primary energy was lowered from 482 to 142 kWh/m^2/year, and CO_2 from 115 to 32 kg CO_2/m^2/year, with \$83,000/yr (€50,000/yr) energy cost savings. (Richarz 2007)
California EPA Headquarters, Sacramento, CA, USA. Built 2000, Refurbished 2003. Temperate	High-rise 25-storey Office building of 88,000m2 (950,000-square-foot). Wanted upgrade for energy use, equipment, water, waste and occupant behaviour.	\$750,000 (US \$500,000)	1. Used recycled and durable materials. 2. Native, drought-resistant grasses, plants, and trees minimise storm water runoff, reduce heat build up and lower water needs.	1. Highly efficient HVAC and lighting systems 2. New photovoltaic rooftop panels 3. A plate and frame heat exchanger to save energy and extend equipment life. 4. Worm farm	First Platinum LEED for Existing Buildings. Created employee incentives and a facility layout to encourage waste reduction, walking, cycling, carpooling, and alternative-fuelled vehicles. Annual savings of \$914,000 (US\$ 610,000). (LEED 2006)

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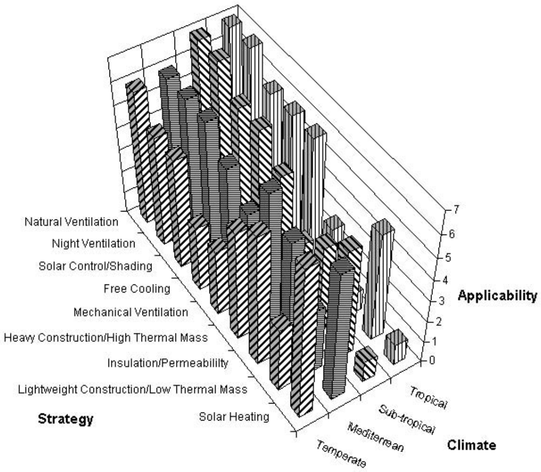
FIGURE 2. The Applicability of Energy-Efficient Building Strategies by Climate Zones.



to those of our most populous cities (UNEP-2 2007 and YHTM 2008). While these are for new buildings, they are also relevant for refurbishments. The Tropical climate includes Darwin and Townsville, the Sub-tropical climate includes Brisbane and the Temperate climate includes Adelaide, Melbourne, Perth and Sydney.

Figure 2 indicates that in Tropical and Sub-Tropical climates, Natural and Night Ventilation are important, with Shading, Free Cooling (where HVAC equipment uses external weather conditions to cool the water instead of electricity), with Lightweight Construction/Low Thermal Mass next in importance, and then Insulation, with little applicability for Solar Heating in cooler times. This contrasts with Temperate climates where Solar Heating is important, followed by Insulation and Natural Ventilation, then Heavy Construction/High Thermal Mass, Night Ventilation and Shading.

4.10 Government Policies

Government policies and regulations are very important because ". . . many building industry professionals only adopt new practices if they are required by regulation." (WBCSD-1 2007)

A review of around 60 policy evaluation studies from over 30 countries and regions, identified government policies that saved building GHG emissions and that were easy to implement and enforce as well as cost-effective (Urge-Vorsatz 2007 and IPCC 2007). Of the 20 best practice policies, the most effective and affordable ones were:

- appliance standards—to improve equipment efficiency, information and communication
- energy-efficiency obligations and quotas—new energy-efficiency measures with short-term incentives
- demand-side management programmes—reducing energy use, costs of great benefit to the commercial sector
- cooperative procurement—for government agencies eg. to leverage expert skills
- energy-efficiency certificate schemes—includes building audits and needs institutional support
- tax exemptions/reductions—to encourage envelope refurbishments and equipment upgrades
- mandatory labelling and certification—can lead to large GHG savings with building certification
- public leadership programmes—to demonstrate new technologies and practices.

An example of a best practice energy-efficiency obligations policy is a refurbishment subsidy that increases with decreases in emissions for owners of houses built before the energy-performance code clauses in Germany (ACE 2008).

Another large opportunity for policy review is in the electricity industry, as noted in Section 4.4.

4.11 Other Stakeholder Behaviour

Building operational stakeholders form a complex network of regulators, developers, owners, owner/occupiers, tenants, suppliers, financiers and building managers, increasing the difficulty of GHG refurbishments (WBCSD-1 2007).

Best practice regulator policies and examples were presented in the preceding section, whereas best practice examples of practical behaviour of other stakeholders to save GHG emissions include:

- owners of large commercial and retail organisations and building managers participating in energy efficiency projects eg. the Existing Buildings Project where the Total Environment Centre and 25 commercial property organisations are upgrading 70 office buildings throughout Australia's major cities (TEC 2007),

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- energy supply companies (ESCOs) that use smart meters with higher peak rates eg. to reduce air conditioning,
- financiers such as KfW in Germany who provide low cost finance for energy-efficient refurbishments (Steinmuller 2008), and
- owner/occupiers and tenants who consider GHG emissions in a lifecycle manner when purchasing building-related goods and services eg. householders in Transition Towns (low resource transitioning) (Hopkins 2008).

Good examples of building occupant behaviours are to purchase 100% greenpower (supplied from purely renewable sources); to buy energy-efficient appliances; to compost or use worm-farms for converting green waste to fertiliser; to grow plants including food to filter CO_2 from the air and save *food miles*, the distance that food travels with related transport GHG emissions (Holper 2008); to eliminate stand-by power, including computers; to develop a User Manual for occupants; and for tenants to sign up to a green lease, where additional environmental requirements are contracted eg. for fitout and operation, purchases, recycling and waste.

In addition, good examples of *house and apartment* occupier behaviours are:

- to use warm/cold instead of hot/hot clothes washing modes,
- to minimise use of pool pumps, dishwashers, clothes dryers, air conditioners, and
- to work from home where possible.

Good examples of *commercial* owner/building manager behaviours are (ARUP 2008):

- to label light switches across zones, and
- to check settings on HVAC equipment.

Opportunities for refurbishment are 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).

5. DISCUSSION

From Figure 1, it is evident that the US, the EU and China are the major primary energy consumers for buildings, and that residential properties are a greater problem than commercial ones. Developing nations such as China and India use more biomass fuel with fewer GHG emissions.

Worldwide the longevity of buildings is decreasing (WBCSD-1 2007), and this trend may be halted with practical refurbishment strategies.

The behaviour of building occupants beyond usage patterns of the building services plays a significant role in the extent of GHGs emitted. Waste emissions can be lowered by recycling and by using compost heaps and worm-farms to fertilise plants that can consume CO_2 and even produce food, reducing *food miles.* Occupant transport emissions can be decreased by encouraging cycling and smaller or fewer cars eg. with car pooling.

The case studies for best practice strategies in Table 2 are from Germany, Switzerland and the USA, and demonstrate that GHG emissions can be dramatically reduced, even economically with 70% energy savings.

The common strategies in Table 2 include external insulation; double and triple glazing; removal of thermal bridges; ventilation heat recovery; CHP for heating and cooling; and PV panels for renewable power generation. In Section 4.3, McKinsey noted that net positive investments in Australia were possible over the lifetime of GHG reduction strategies, particularly in the areas of lighting, stand-by power, commercial HVAC and residential hot water systems.

Stakeholder behaviour is very important and policies and strategies suggested in Section 4.10 and 4.11 could assist greatly in lowering GHG emissions. Education about the effect of appropriate house size on GHGs would assist as well, since there is a significant trend towards larger sized house construction and renovation, as well as the number of people living in houses decreasing.

Energy-efficient refurbishments should use low embodied energy materials that are sourced locally and constructed using sustainable construction techniques.

5.1 Strategies for Australia

Section 4.9 contains strategies for buildings in climates relevant to large cities in Australia, and Section 4.11 gives strategies for various stakeholders and across building types.

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Table 1 indicates that electricity used in buildings will have higher emissions in Victoria, NSW and Queensland, and so buildings in these states should get refurbishment priority. Also, electricity reform is a good candidate for government policies as Section 4.4 notes.

Refurbishments, as well as new buildings, should be designed in an integrated and holistic manner, and employ Passive building techniques to achieve synergies for greater GHG emission reductions by optimising the envelope, services and stakeholder strategies across many disciplines.

Buildings are usually designed with a single lifetime in mind, and for specific activities, with little regard to future change of usage and ownership. So building components, such as walls, windows, ceilings and floors, should be re-evaluated using lifecycle analysis. Then a maintenance programme should be established for them similar to a services maintenance programme, to ensure that the building remains in service for as long as possible, even with usage changes, by servicing or replacing the components in a flexible manner as technology and methods improve eg. adding exterior or cavity insulation to walls.

Renewable fuel sources such as 100% greenpower, PV or Wind Turbines can be used once GHG emissions have been reduced, to minimise or cancel the remaining emissions.

Australia should adopt the government polices recommended as described in Section 4.10, particularly demand-side management programmes such as feed-in tariffs, and more incentives and tax exemptions/reductions that would encourage substantial GHG emission reduction refurbishments across the commercial and residential sectors.

When a Carbon Emission Trading Scheme is introduced in Australia and the cost of energy from fossil-fuels increases, more GHG reduction strategies will become cost-effective.

5.2 When to Undertake Australian Refurbishments

Buildings, and particularly housing, closest to public transport should receive priority for refurbishment, complying with the local planning consolidation development policy, lowering GHG emissions due to more medium density properties eg. dual occupancies, and with less private transport.

From Section 4.3, almost all of Australia's existing building stock has not been designed for energy performance, and buildings still standing in 2030 ie. built since 1930 in the more populous states with the higher electricity GHG factors of Table 1, such as Victoria, NSW and Queensland, would be very good candidates for refurbishments.

Since occupant behaviour has a large effect on a building's GHG emissions, priority should be given to inform occupants of better GHG behaviour by introducing information sessions; encouraging occupant participation with their own suggestions; and creating User Manuals that would include the strategies mentioned in Section 4.11. In addition, the User Manual could highlight GHG-saving ideas such as minimising services and resources eg. electricity and air conditioning by zoning (having areas with separate switches or partitioned off); HVAC management; Car Park management; advice on lighting tubes/bulbs, waste procedures including recycling, purchasing of environmentally-friendly office capital equipment and its management; promotion of recycled consumables eg. printer/copy paper and ink; and fitout and refurbishment guidelines eg. for non-toxic paints and glues.

As noted in Section 4.5, building types could be identified that consume high intensity of energy or high total energy to raise their priority for refurbishment.

Section 4.11 also identified some criteria by EIE (2007) for when to carry out a refurbishment. Additionally, refurbishments may be undertaken when tenants wish to share some costs and risks including by taking on a green lease, or when subsidies or grants are won to offset the refurbishment costs.

6. CONCLUSION

The existing building stock deserves special consideration to reduce GHG emissions, since the emissions are 30–40% of global energy consumption, and for Australia, the source of that energy is largely from fossil fuels producing high Greenhouse Gas (GHG) emissions. Around 80% of a building's energy consumption occurs during the operational phase, and overseas experience shows refurbishment energy savings of 50–70% including some with short payback periods.

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The housing sector has the major share of emissions and so needs urgent attention, although it has a complex stakeholder network and so is a difficult one in which to carry out GHG emission reductions. This paper has identified significant occupant behaviour GHG emissions, and provided some best practice strategies from energy-efficient regions around the world so that stakeholders in Australia may be able to apply some of these technologies and approaches according to building type and climate.

Further research is required for strategies with their costs, savings and longevity across more building types; for building types that are more GHG intensive; for special consideration of heritage buildings; for existing government policies and rebates; and for finding criteria for refurbishing rather than demolishing. These are the directions that the author's research is currently heading, and feedback is appreciated.

8. ACKNOWLEDGEMENT

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