A Challenge to Sustainably Improving Environmental Performance of Existing Housing Stocks in Australia

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Abstract

A key global challenge nowadays is to address climate change and reduce greenhouse gas emissions. Climate change is one of the most pressing issues facing Australia today. Improvements to energy and water efficiency of existing building stocks can significantly cut greenhouse gas emissions and reduce utility bills. With increasing recognition that green buildings outperform conventional buildings, much less known about how green building initiatives can be incorporated into upgrading existing housing stocks. In Australia due to population growth and increased in the size of dwellings coupled with the reduction of number of person per household have put an enormous pressure on energy and water consumption. Existing houses represent approximately 98% of residential building stocks and any improvement to these dwellings will have a profound impact on reducing the negative effects of the environment. This paper examines the sustainable upgrading strategies in improving environmental performance of three existing single dwellings. This paper presents an economic analysis of sustainable upgrading using Net Present Value. The results suggest that sustainable upgrading of existing housing stocks is feasible and the scheme will be more attractive if more government financial assistance is provided.

Keywords: sustainable upgrading, BASIX, sustainable house

1. Introduction

A key global challenge nowadays is to address climate change and reduce greenhouse gas emissions (Phillips, 2008). The building sector is increasingly aware of the vulnerability of buildings to the sustainability agenda. Of particular concern is the fact that the building sector is responsible for approximately 23% of Australia's total greenhouse gas (GHG) emissions (CIE, 2007). Building sustainably provides a way to significantly mitigate environmental impact (CIE, 2007). Previous research has concentrated on the sustainability of new buildings and has developed strong business cases for green buildings. Many support the idea that inefficient existing buildings should be demolished to make way for new and more efficient buildings (Boardment et al., 2005). Demolishing existing buildings and replacing them with new ones is largely preferable in many cases since it is often expensive to upgrade and difficult to make them to meet sustainability standards (Boardman et al., 2005). A key foundation of this argument is that GHG emissions of highly efficient new buildings is far lower than the buildings built in the past due to effective use of insulation and modern technology. However, opponents maintain that new buildings consume natural raw materials and energy in the development which could have been saved by reusing existing buildings (Bullen, 2007). In addition the large amount of carbon embodied in existing buildings, the energy required in demolition and disposal of waste, and the energy required for extraction, production, transport and use of new materials are significant factors (Ireland, 2008).

As new construction activity in the market averages less than 2% of the building stock the importance of focusing on maintenance and refurbishment of existing buildings needs to be emphasised (Bullen, 2007; Power, 2008). With the current rate of rebuilding it would take 50 to 100 years to replace the current building stock whilst existing buildings will continue to perform inefficiently and pollute the environment. In support of this, there are growing calls for the upgrading of existing buildings and even to completely stop new construction to limit the wastage of scarce resources (Kohler, 1999). In Australia there is a significant switch from new buildings to the adaptation and rehabilitation of existing structures. The importance of this trend is to extend the useful life of existing buildings that support the key concepts of sustainability by reducing virgin material consumption, transport and embodied energy, and pollution (Ireland, 2008; Power, 2008).

This paper is intended to shed light on energy and water consumption of Australian homes and the development of strategies to improve the environmental performance of existing housing stocks. It summarises the discussions and arguments, and attempts to clarify the direction towards major reductions in water and energy use in homes. The paper aims 1) to gain a deeper understanding on issues related to refurbishment of existing housings as opposed to new build, 2) to review the current situation of sustainable housing in Australia, 3) to assess and compare environmental performance of three properties of similar size but differing ages in New South Wales (NSW), Australia .4) to examine the conversion strategies in improving environmental performance in meeting the minimum BASIX requirements, 5) to present the research result.

2. Environmental performance of residential buildings - refurbishing or demolishing

Building green has become a standard building practice in the construction industry nowadays. Demolishing an inefficient property may seem to be the best way of reducing energy use and to make way for more new buildings as it is often expensive to upgrade and difficult to refurbish existing houses to meet sustainability standards (Boardman et al., 2005). A key foundation of this argument is that greenhouse gas (GHG) emissions of highly efficient new housing can be far lower than the houses built in the past due to effective use of insulation and the latest technology. This is the underlying principle of the 40 percent house argument in advocating the demolition of a total of 3.2 million houses from 2005 to 2050 (Boardman et al., 2005; Power, 2008). Demolishing houses built in the past is considered to be a way to improve environmental efficiency.

With increasing recognition that green buildings outperform conventional buildings in terms of environmental, social and economic aspects, much less is known about how green building initiatives might be incorporated into existing buildings and little work has been done to examine how existing buildings should be maintained and refurbished for sustainability. If the challenges of climate change and reduced GHG emissions are to be successfully tackled, there is enormous potential to maintain and refurbish the existing building stocks in order to make the current built environment more environmentally-friendly and energy efficient (Bromley et al., 2005; Bullen, 2007). The existing building stock has the greatest potential to lower the environmental load of the built environment significantly within the next 20 or 30 years (Bullen, 2007). Recent research suggests that sustainable maintenance and refurbishment of existing buildings use 23% less energy than new construction (Mickaityte et al., 2008). Moe (2007) further suggests that it will take approximately 65 years for a green and energy-efficient building to recover the energy and resources lost in the demolition of an existing building, even if 40% of the building materials from the demolition are recycled. Power (2008) further states that building, demolition and renovation waste make up about one-third of all landfill which is detrimental to the environment. Consequently, sustainable maintaining and refurbishing of existing buildings may be a more practical way to respond to climate change and other negative impacts on the environment.

There have been research into the environmental value of existing housing and results have demonstrated that the maintenance and conservation of existing housing stocks help to achieve environmental gains as these buildings represent a major investment in natural and human resources (SDC, 2006; Ireland, 2008). A research project undertaken by the Empty Homes Agency, UK reveals that refurbishing existing homes can save up to 35 tonnes of CO_2 per property by removing the need for the energy locked into new build materials and construction. The research also reveals that there is not much difference of new built compared with refurbished housing over an operating period of 50 years (Ireland, 2008).

Research undertaken by the UK Government (Cabinet office, 2000) reveals that the energy produced from non-renewable sources consumed in building accounts for about half of the UK's emissions of carbon dioxide. Over 90% of non-energy minerals are used to supply the construction industry with materials. However in each year about 70 million tonnes of construction and demolition materials end up as waste in landfill sites. It is questionable whether the decision to undergo demolition is justified for its energy-efficiency, given that the energy performance of renovated homes can improve significantly over time (SDC, 2006; Ireland, 2008). According to Power (2008) upgrading existing housing stocks can both reduce carbon emissions and environmental impacts of new building through implementing basic energy-efficiency improvement measures including insulation, double glazing, damp-proofing and condensing boilers for heating and hot water.

Despite the increasing recognition for sustainable refurbishment of existing housings there is still strong opposition due to economic constraints and the difficulty to match the sustainable performance of a new house. However despite this there is strong evidence that existing housing stocks has the greatest potential to lower the environmental load of the built environment significantly over the next few decades. The time to convert a building as opposed to new build will have an impact and the work to convert a building will take less time than demolition, site clearance and new build, unless extensive structural alterations or repairs are required. According to some research the cost of refurbishing is generally much less than the cost of new construction, since many of the building elements are already constructed (SDC, 2006). The opposition is further intensified due to the lack of reliable data and methodology to undertake life cycle economic, energy and environmental analysis of building elements, materials and equipments for sustainable maintenance and refurbishment of existing buildings. Little work has been done in these areas. Sustainable maintenance and refurbishment of buildings will require identifying building elements/components that may require regular maintenance, repair and scheduled renovation and their related life expectancy to determine the maintenance cycle over the useful life of the building. However there is a shortage of appropriate, relevant and historical information and data that can be used.

3. Residential energy use in Australia

Australia's total current residential household is expected to increase from 7.4 million in 2001 to 10.8 million dwellings in 2020, an increase of 47% (DEWHA, 2008; ABS, 2009). Population growth and fewer people per household are the driving force behind housing demand. The total residential floor area is expected to rise from 685 million m^2 in 1990 to 1682 million m^2 by 2020, an increase of 145%. The average size of new dwellings is increasingly rapidly since 1986. It is expected to increase by approximately 280% by 2020 while the number of households is only projected to increase by 177% over the same period (DEWHA, 2008). Therefore the per person residential energy consumption has been a steady but modest increase from 17 GJ per person in 1990 to 20 GJ by 2020, approximately a 20% increase. The increase is partly being driven by a decline in the number of person per household.

Australians are high energy users. Energy consumption was around 5,688 PJ in the 2005-6 and is expected to rise to 6,479 PJ in the 2011-12 year, representing an increase of 14% (Department of Climate Change, 2009). In Australia, about 95% of the energy comes from burning fossil fuels, causing GHG emissions (Energy Task Force, 2004). This energy production and use contributed 68% of Australia's GHG emissions and is expected to grow to 72% by 2020 (Energy Task Force, 2004). Approximately 25% of Australia's GHG emissions derive from energy consumption in the residential sector. According to the estimate of the DEWHA (2008) residential sector energy consumption has increased from 299 PJ in 1990 to 407 PJ in 2009 and is projected to increase to 468 PJ by 2020 under the current trends, an increase of 56%. The use of electricity as a major source of energy will also increase from 46% in 1990 to 53% in 2020. This will significantly contribute to the growth of GHG emissions. The use of gas whilst increased over the years is still small at 35% compared to electricity at 52% in 2009.

Each household in Australia on average produces more than 15 tonnes of GHG per year which contributes to approximately 20% of Australia's total greenhouse gas emissions (Reardon, 2004). The largest source of greenhouse gas emissions from households is from energy used to heat, cool, cook, provide lighting and run household appliances, accounting for approximately 42% of total energy consumption per household (Reardon 2004). Hot water heating represents about 30% of home energy use (Blazey & Gillies, 2008). Energy demand for heating and cooling is projected to increase despite the introduction of minimum building shell performance standards. The main factors driving this trend include the floor area of the average new dwelling continues to exceed that of the stock average. The building shell performance standards only affect approximately 2% of the total stock per annum.

The energy consumption of electrical appliances has increased over the years. It consumes of approximately 17% of energy consumption but more than 25% of CO_2 from homes (SDC, 2006). In Australia the growth in electrical appliance energy consumption was the largest among major end users and was estimated to increase from 71 PJ in 1990 to 170 PJ in 2020, an approximately 5% average growth per annum. By 2020 electrical appliance energy use is forecast to almost match space heating as the largest single energy use in the averages Australian households (DEWHA, 2008).

Existing housing stocks in Australia are not sustainable and the NSW government is convinced that sustainability is the only way forward. In NSW sustainable housing is an important focus of the government's housing policy. In response to the need for sustainable housing the government launched a sustainability assessment tool called BASIX in July 2004 as mandatory to all new residential developments. The introduction of BASIX has a profound impact on the environmental performance of new dwellings (Ding, 2007). All new residential buildings have become more environmentally friendly since the introduction of BASIX. The impact is not confined to building practitioners but has also raised awareness amongst home users. However BASIX does not apply its standards to existing housing stocks. That means the existing housing stocks will continue to impact on the environment for the next few decades. More work needs to be done to sustainably upgrading the existing housing stocks so that it can progress to reduce negative environmental impacts. As discussed previously sustainable upgrading of existing housing stocks is a key foundation to achieving the goal of ecological sustainable development.

Table 1 – Summary of rebate schemes from the Federal and NSW state government

Item	Rebate ($)	Sources	Details	Duration
Solar bonus scheme	0.60 per kWh	NSW	Solar photovoltaic and wind power up to 10kW	7 years from 2011
Rainwater tank	150 - 500	NSW	Purchase and install rainwater tank	1/7/2007 to 30/6/2011
	400 - 500	Federal	Purchase and install rainwater tank	Since 1/3/2009
	500	Federal	Permanent greywater treatment system	Since 1/3/2009
	500	NSW	Rainwater tank connection to toilets	1/7/2007 to 30/6//2011
	500	NSW	Rainwater tank connection to washing machines	1/7/2007 to 30/6/2011
Hot water system	300	NSW	Gas hot water system with a 5 Star or higher energy rating	15/1/2010 to 30/6/2011
	300	NSW	Solar or heat pump hot water system	15/1/2010 to 30/6/2011
	1,600	Federal	Solar hot water system	Since 3/2/2009
	1,000	Federal	Heat pump hot water system	Since 3/2/2009
Hot water circulator	150	NSW	Install with a new or existing instantaneous gas hot water system	15/1/2010 to 30/6/2011
Insulation	1,200	Federal	Ceiling insulation	Until 31/12/2011
Washing machine	150	NSW	New washing machine of at least 4.5 Star rated	15/1/2010 to 30/6/2011
Dual flush toilet	200	NSW	New dual flush toilet suite with a water rating of 4 Star WELs rating or higher for both the cistern and the pan	15/1/2010 to 30/6/2011
Fridge	35	NSW	Removal of domestic old second fridge	Until 2011

Sources: Department of the Environment, Water, Heritage and the Arts (http://www.environment.gov.au/rebates/index.html)
Department of the Environment, Climate Change and Water (http://www.environment.nsw.gov.au/rebates/index.htm)

In response to the need for sustainable improvement of existing housing stocks, a range of federal and NSW state economic schemes have been introduced to encourage the adoption of sustainable building design features and construction strategies. These rebate schemes subsidize to a minor extent the construction of new dwellings. They operate far more widely than compulsory buildings codes to encourage the owners of existing dwellings to adopt sustainability strategies. The Federal government rebate scheme was operated under the Energy Efficient Homes Package and National Rainwater and Greywater Initiative by the Department of the Environment, Water, Heritage and the Arts. The NSW state rebate scheme was operated under the NSW Home Saver Rebates since July 2007. Table 1 summarises the rebate schemes from the federal government and the NSW state in Australia.

4. Research method

NSW is one of the largest states in Australia and has the highest growth in both population and energy consumption. NSW is experiencing increased residential construction activity as a consequence of continual urban growth coupled to the decline of average Australian household size (2.6 person in 2006 compared with 3.3 persons in 1976) and the increase in average floor space of approximately 3% over the last 7 years has imposed significant pressure on the environment (ABS, 2009). NSW is the largest energy consumer in Australia accounting for about 28% of final energy consumption, representing a total of 921 PJ in 2000/1, and it is expected to grow by an average of 2.3% each year to 2019/20 (Standing Committee on Public works, 2004). Residential energy consumption makes up 13% of total energy consumed in

NSW and has risen approximately 20% across NSW over the last ten years due to population growth and the increasing demand of housing (Standing Committee on Public Works, 2004).

The purpose of the research was to explore how sustainable upgrading of existing housing stocks is a way toward achieving ecologically sustainable development. Three case studies were chosen in the northern suburbs of NSW. They were all detached family houses of roughly similar in size and layout but were built in different years using traditional construction methods. The research was a pilot study to gain a better understanding of the total energy and water consumption, and CO_2 emissions in running a family house. At this stage only the operational (in-use) consumption and CO_2 emitted in the everyday occupation of the houses were measured. The embodied energy and CO_2 emission in the materials will not be included in the next stage of the research. Table 2 summarises the background information and the utility consumption on the three case studies from 2004 to 2008.

Table 2 – Summary of details for case studies

	House A	House B	House C
General details			
Location (Suburb)	Wahroonga	Pennant Hills	Hornsby
Land area (m^2)	432	835	542
GFA (m^2)	180	165	229
Type	4 Bedrooms	4 Bedrooms	4 Bedrooms
Age (years)	17	30	5
Construction details	Brick veneer with slab on ground, tiled roof	Brick veneer with suspended timber floor, tiled roof	Brick veneer with slab on ground, tiled roof
Family member (No)	4	3	3
Summary of utility consumption for 2004 to 2008			
Gas Monthly average (MJ) Yearly average (MJ)	 1,647 19,769	 2,877 34,525	 1,543 18,512
Electricity Monthly average (kWh) Yearly average (kWh)	 437 (1,573 MJ) 5,241 (18,868MJ)	 365 ((1314 MJ) 4,381 (15,772 MJ)	 383 (1,379 MJ) 4,597 (16,550 MJ)
Water Monthly average (KL) Yearly average (KL)	 14 172	 23 270	 12 146
CO_2 emission p.a. (kg)	5,625	5,053	4,957
CO_2 emission/person/yr (kg)	1,406	1,684	1,652
Summary of expenditure of utility consumption for 2004 to 2008			
Gas Monthly average ($) Yearly average ($)	 36.90 442.75	 55.20 662.40	 35.68 428.14
Electricity Monthly average ($) Yearly average ($)	 57.35 688.19	 49.83 597.92	 51.29 615.46
Water Monthly average ($) Yearly average ($)	 55.05 660.60	 64.75 776.97	 52.79 633.45

The three houses have been initially inspected to assess the current conditions and to identify areas of improvement. The environmental performance of the three houses has also been assessed using BASIX to consider the performance so as to develop a sustainable direction for upgrading to improve environmental performance and to comply with BASIX requirements. The costs of sustainable upgrading has also be analysed in conjunction with the available government rebates. The analysis highlights the minimum upgrades the property would be required in order to comply with the BASIX benchmarks for new residential development. The utility consumption was assessed for five years from 2004 to 2008 and included in Table 2.

5. Observations and analysis

5.1 Performance assessment

Gas, electricity and water bills were collected for the three houses for the past five years and details are summarised in Table 2 and graphically presented in Figure 1. The table presents the gas, electricity and water consumption on a monthly and yearly basis and the figures present the data on a quarterly basis. From Figure 1, on average Q2 and 3 have the highest gas and electricity consumption. There is a clear cyclical and seasonal pattern characteristic of the increased demand for heating during the winter months followed by reduced demand during the summer months.

From Table 2 the annual gas consumption of House B was the highest whilst the annual electricity consumption of House A was highest. The three houses consume 3220 MJ, 4191 MJ and 2922 MJ respectively for House A, B and C with House B having the highest energy usage, approximately 23% and 30% more than House A and C respectively. However the CO_2 emissions of House A outweigh the other two houses to be the biggest emitter of 5625 kg of CO_2 per year, approximately 11 to 13% more than the other two houses. Even though House B was the uppermost energy end user, approximately 69% were from gas and gas has much lower CO_2 emission than electricity. Nevertheless if the number of household members were taken into account House A has the lowest annual CO_2 emissions of 1406 kg per person whilst House B has the highest annual CO_2 emissions of 1684 kg per person, approximately 20% more than House A. The analysis of energy consumption from the utility bills was only the secondary energy consumption. There may have wastage and loss in the production and delivery processes from the production side to the side of the consumers where insufficient information is available for an accurate calculation. The primary energy can be approximately three times more than the secondary energy as electricity in NSW is generated by burning coal. Therefore the outcomes from the analysis may be much worse than they appear to be.

The water consumption as indicated in Table 2 and Figure 1 has not revealed a clear cyclical or seasonal pattern. In annual water consumption House B was the highest outconsuming the other two by almost 40 to 50%. The annual per person water consumption House B has outweighed House A and C by approximately 53% and 46% respectively. The three houses were generally above the benchmarks of energy and water consumption, and CO_2 emissions as set within the BASIX benchmarks.

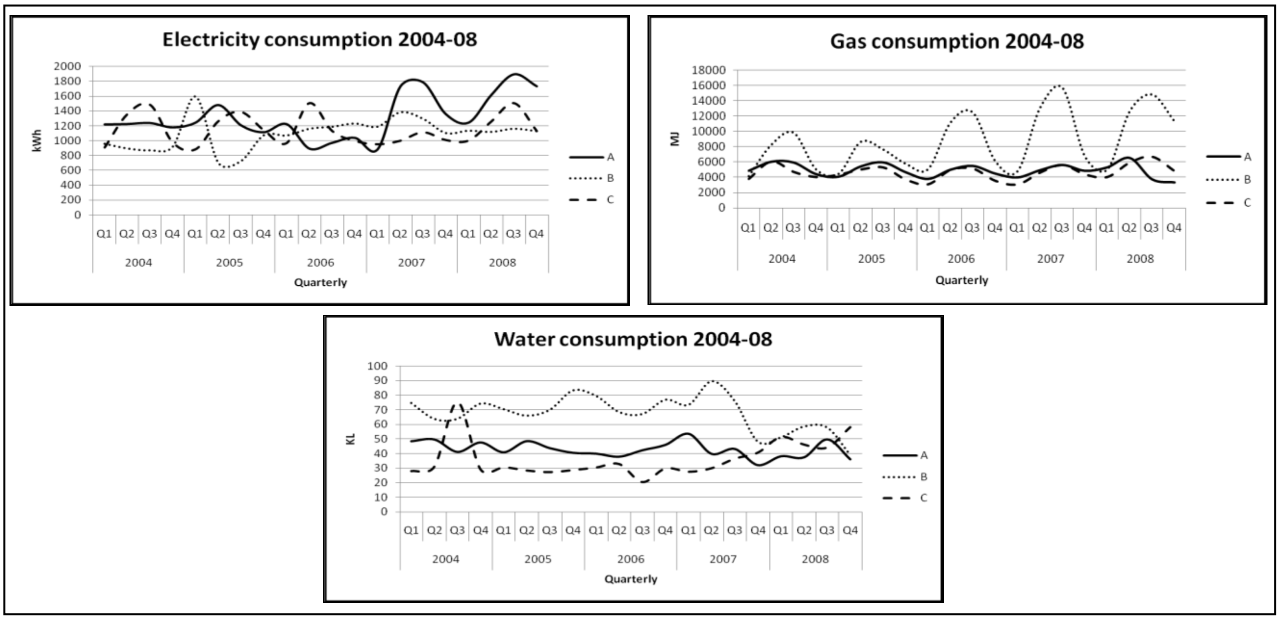

Figure 1 – Utility consumption for 2004 to 2008

BASIX has been used to assess the planning and design of new residential development in NSW since its introduction in July 2004. It has been widely accepted as a benchmark to evaluate environmental performance of residential dwellings. The three houses were assessed using BASIX to determine the performance and used to guide sustainably upgrading for the three houses in the research. The outcomes from the BASIX assessment were used to determine the areas for sustainable upgrading. Table 3 summarise the outcomes of the BASIX assessment which reveals that all three houses passed the thermal comfort assessment but failed the water and energy efficiency appraisal. House B has the worst water score which has only achieved 11% and House C score the worst in energy consumption.

Table 3 – Summary of BASIX scores for House A, B and C

BASIX requirements	Target	Scores		
		House A	House B	House C
Water efficiency	40%	30%	11%	26%
Energy consumption	40%	25%	28%	23%
Thermal comfort	Pass	Pass	Pass	Pass

5.2 Economic analysis and strategies of sustainable upgrading

As discussed previously sustainable upgrading of existing housing stocks plays an important role in tackle climate change. However it will only be acceptable to households if it is affordable. Table 2 summarises the monthly and yearly expenditure on utilities for the three houses. House B has the highest expenditure on utility bills, 12% and 18% higher. Therefore the sustainable upgrading will be attractive if utility bills can be reduced substantially. A sustainable upgrading strategy has been developed after the initial building audit and BASIX assessment for the three houses. It is intended to improve environmental performance of the three houses to comply with BASIX requirements. Table 4 summarises the key sustainable design initiatives proposed for upgrading the three residences to comply with the three sustainability indices addressed by BASIX. There are more initiatives that can be done to further improve sustainable performance of these homes. However more initiatives will incur more costs which will make sustainable upgrading less attractive. Therefore the strategy used was based on the least cost approach to a minimum amount of upgrading that can fulfil the BASIX requirements. The improvements were also focused on the initiatives that government rebates are available so that the upgrading strategy will be more attractive and viable.

Table 4 Summary of key sustainable design initiatives

Initiatives	Description	Remarks
Fixtures and fittings	Upgrade of fixtures to bathroom and kitchen to 5 Star WELs rating including dual flush toilet	All houses
Washing machine	4.5 Star WELs rated	House B only
Rainwater tank	Installation of 3,000 litre rainwater tank to collect water from roof area. Collected water to be reticulated to toilets for flushing and to at least one outdoor tap to service the garden of the residence	All houses
Solar hot water system	Replace existing electric storage hot water system	House B only. Both House A and C have already installed with gas hot water system.
Hot water circulator	Install to all hot water systems	All houses
Light fittings	Upgrade of existing light fittings to be energy efficient	All houses
Insulation	Installation of ceiling insulation, R-Value 3.0, including 2 No wind driven ventilators	House A and C only as House B is not eligible with the installation of a solar hot water system.
Shading devices	All windows to have blinds to improve indoor comfort	All houses

Table 5 summarises the outcomes of analysis of sustainable upgrading using the following formula:

$$\text{NPV}=\sum_{t=1}^{n}\frac{C_t}{(1+r)^t} \qquad (1)$$

C_t = net cash flow expected at time period t n = project life span
r = selected discount rate t = the time of the cash flow

Table 5 – Summary of cost-benefit analysis of sustainable upgrading for the cases

	House A	House B	House C
Discounted costs $ (less government rebates)	8,779	9,752	9,753
Discounted benefits $	12,017	9,414	11,870
NPV ($)	3,238	-338	2,117
IRR (%)	10.405	4.445	8.195
Payback period (year)	17	25	19

The analysis was undertaken on a life span of 30 years at a discount rate of 5%. The improvements have been calculated based on current market rates less the respective government rebates. The NPVs suggest that the sustainable upgrading be accepted as the NPVs are positive and the IRRs are greater than the required rate of return. Only House B has negative NPV and IRR less than the discounted rate which has demonstrated that the sustainably upgrading is not a feasible option for House B. The payback periods were all more than 15 years with House B the longest at 25 years. The long payback period has eventually reduced the attractiveness of sustainable upgrading in the study. However the proposed sustainable upgrading has represented the least that need to be done to satisfy the BASIX assessment and more may be required to match the standards of new houses. The three projects were re-assessed in BASIX and amendments were incorporated into the original assessment. Eventually all three projects passed the three sustainability benchmarks addressed in BASIX.

The results have demonstrated that sustainable upgrading of existing dwellings is not an attractive option at this stage with the current level of government rebate incentive. It impacts on the affordability of sustainable upgrading even though households are aware of the importance of sustainable development. Economic instruments are important drivers in achieving efficiency. BASIX is now mandated only to assess new development and many suggested that it should be improved and extended to assess existing residential dwellings as it will have a more profound impact on the reduction of CO2 emissions. However should such a goal be successful it will be strategically important that the government provide more incentive schemes to support affordability in sustainable upgrading.

6. Conclusions

The analysis of the utility consumption from 2004 to 2008 for the three cases draws parallel with the areas where the dwellings failed in the initial BASIX assessment. This paper has examined the direction for sustainable upgrading and has also presented an economic analysis alongside with the government financial rebates to pass the BASIX assessment. The three houses represent a typical family home in NSW, Australia. Even though a sample of three houses may be considered a small sample size, the results will provide an understanding on the current environmental performance of each household and its impact on the environment. Consequently a sustainable upgrading strategy to the existing housing stocks can be derived to tackle climate change. The environmental impact of an individual house may be minimal but considering the effects of all the houses together they will make a significant impact to the environment. More work needs to be done to reduce the environmental impact of existing housing stocks. It will be fundamental if statutory requirements such as BASIX can be extended to existing residential buildings.

The study has revealed that upgrading to improve efficiency of existing housing stocks is an ideal and feasible solution to reduce greenhouse gas emissions and depletion of natural resources. The upgrading strategies for the three houses were developed using BASIX requirements as benchmarks. The main focus for upgrading was to install insulations to optimise the building fabric and mitigate heat loss and heat gains through the roof. The scheme also includes the installation of a solar hot water system and hot water circulator to reduce consumption of non-renewable energy. Energy saved will result CO_2 emissions through a reduced demand for heating and cooling. The water efficiency was improved through upgrading of fixtures and fittings, and the installation of a rainwater tank to reticulate harvested water for toilet flushing, laundry and irrigation. The study has also revealed that sustainable upgrading is achievable but with a cost that may eventually decrease the motivation to improve sustainably. The incentive to consider sustainable upgrading will largely depend on whether the cost of upgrading can be offset by the potential savings and the available government financial assistance. The long payback period of upgrading of the three cases has demonstrated that more government financial assistance may be required to encourage more sustainable upgrading.

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