Life Cycle Energy Analysis of Residential Building Retrofits Incorporating Social Influences

Melissa Gaspari[1]

Abstract

Retrofitting is a front-runner in sustainable options to improve residential lifecycle energy consumption as Australia's home energy use rises. Over the past 20 years there has been a growing trend for larger houses within Australia; combined with the residential sector being responsible for 7% of Australia's energy use, the need to improve our current housing stock is hard to ignore.

The average household is overrun by various rebates, technology, and fashionable quick fixes to improve their home's energy efficiency, but how do these households choose? This paper explores the way Life Cycle Energy Analysis supports decision-making when retrofitting for energy efficiency and incorporates how social influences, such as age, income, goals, time constraints, thermal comfort, gender and technology factor into the way homeowners prioritise their retrofitting options.

Current research identifies many different approaches to using Life Cycle Analysis to support decision-making in retrofitting. However, few have addressed the influence of social aspects. This research incorporates the human and social aspects into a decision-support framework. This framework uses Life Cycle Energy Analysis as a tool to support decision-making and intends to identify a means to align the most effective life cycle improvements to the social intentions, objectives and constraints of homeowners. Using information gathered from interviews with over 10 different homeowners, the framework integrates the real life scenarios to outline the social effects, whilst simultaneously allowing homeowners to meet their needs and still consider energy efficiencies and improvements over the lifetime of their home.

To fill the gap in connecting social aspects with lifecycle decision-making this paper is designed to incorporate energy efficiency into the decision matrix using Life Cycle Energy Analysis, while supporting the social objectives of homeowners over the entire lifecycle of an Australian residential building.

Keywords: Sustainability, Life Cycle Energy Analysis, Social Influences, Retrofit, Residential.

---

[1] Graduate Honours Student; University of Wollongong; 59/6-10 Eyre Street Griffith, ACT 2603; melissa.gaspari@gmail.com

1. Retrofitting Residential Buildings

Retrofitting is an attractive option to improve residential life cycle energy consumption in Australia; it is an emerging industry helping to determine how the energy use of an existing home can be reduced. This concept of building retrofit is more commonly seen in commercial buildings, and has been proven to lead to considerable reductions in energy use (Yohanis and Norton, 2002).

Life Cycle Analysis (LCA) is one technique to assess the environmental aspects and potential impacts of products from raw materials to production, end use and disposal (Australia/New Zealand Standard, 1998). Life Cycle Energy Analysis (LCEA) uses this same approach with energy being the only indicator. One of the key components of a LCEA is embodied energy. That is, the energy used in the production of the materials and a significant contributor to the amount of energy used to complete a retrofit (Hogan, 2011). For this reason, studying the outcomes of LCEA of retrofit options should include embodied energy, operating energy (the energy consumed during a buildings lifecycle), as well as maintenance and disposal energies, in order to provide a complete insight into the most energy efficient options. LCEA may be used to assist in decision-making for many factors including social influences and gives a comprehensive cradle-to-grave appraisal (Australia/New Zealand Standard, 1998).

The existing housing stock in Australia requires significant retrofit as it currently threatens to be the biggest liability in long-term energy efficiencies. Approximately 2% of new housing is constructed each year in Australia, leaving 98% of the existing housing stock to be retrofitting or retired (Department of the Environment, 2008). Of this only approximately 80% of housing is occupied –3.3% of which is already undergoing retrofit or renovation and only 1% is being retired - leaving over 75% of the existing housing market open to some form of energy retrofit and improvement (Department of the Environment, 2008).

Behavioural attitudes, climate, housing size, occupancy, level of education and other social influences affect the overall energy consumption of a home, and although some homes may be deemed to require energy retrofit, they may consume less energy in their operation than others due to their occupants. Climate zones offer static parameters and many retrofitting options can be used across multiple climate zones, highlighting that behavioural attitudes or social influences will have the greatest impact on results. The most effective retrofit options are limited without knowing the exact conditions of the existing housing stock that requires retrofitting.

The implications of social factors in this study will be the most notable, as they will provide an insight into decision-support of retrofitting options. LCEA can incorporate these parameters to provide a whole of life evaluation, providing an insight into retrofitting options for the existing Australian housing stock.

1.1 LCEA as a decision support tool for building retrofitting

A recent study, *Comparing life cycle implications of building retrofit and replacement options,* discusses the question of when it is best to retrofit a building rather than rebuilding it (Dong, Kennedy *et al.*, 2005). Typically, LCEA models and tools are aimed towards improvements in design of new dwellings. However, with the large stock of existing residential buildings, this attention has recently shifted toward energy retrofit (Dong, Kennedy *et al.*, 2005).

To analyse a whole of life approach Dong, Kennedy *et al.*, (2005) use a LCEA methodology, with a series of environmental indicators, (global warming potential, waste, water pollution, cost, economic indicators as well as energy), highlighting the parameters and context of this LCEA. LCEA supports the decision-making process in this analysis, as the conclusions of this study show that, despite the high energy saving in rebuilding at any one stage, the waste produced by this process is severe. This concludes that in the context of one of the indicators, waste, the views of LCEA can be altered and the impacts varied from the initial energy assessment.

Reductions in both embodied energy and operational energy need to be balanced in order to identify the whole life cycle energy efficiencies. When determining retrofit options, indicators provide alternative ways of analysing this balance. LCEA uses energy as the singular indicator in this balancing process. Ramesh, Prakash *et al.,* (2010) emphasise this in their research of seventy-three case studies from thirteen different countries, considering the energy consumption of either conventional or low energy buildings. Their analysis of both the operating and embodied energy highlighting the significance each energy phase has on the overall building life cycle energy.

This research indicates the usefulness of the LCEA approach in determining energy savings, and is paramount to the decision making processes. Trade-offs and balancing energy phases is crucial in LCEA.

1.2 Indicators for Life Cycle Energy Performance

Indicators used for life cycle performance aid in determining environmental impacts. LCEA is rarely completed alone, often using key indicators, impact assessments, or characterisation factors to help identify the full influence of the choices at hand and the long-term effects. Existing research presents a number of commonly used indicators and impact assessments, as per AS/NZS ISO 14042,yet for the purpose of this research, indicators that will be used in the decision making process, will be social influences and energy.

Research completed by Peter Clinch and Healy (2003) explore the single factor of comfort, which focuses on LCEA of energy-efficient retrofits in Ireland. This research further defines the limitations and impacts of this indicator (comfort). Peter Clinch and Healy (2003) discusses the clear trade off indicators create, most importantly illustrating the limitations of various indicators and factors in their analysis. Emphasising the individualistic nature of home ownership and retrofit decisions, Peter Clinch and Healy (2003) conclude that dependant on these individual characteristics, what may have initially been retrofit for

energy, may not decrease energy consumption, but instead, increase comfort (or an alternative factor).

One key perspective that needs to be considered is the national code of building construction, known as the Building Code of Australia (BCA). Morrissey and Horne (2011) suggest that the minimum standards set in the BCA do not necessarily promote the most cost effective options available when constructing a home, or updating an existing home to meet the current standard. Although the BCA sets the minimum code for energy efficiency, it is suggested that LCEA combined with exceeding the BCA requirements provides a more cost effective energy choice for a greater time period (Morrissey and Horne, 2011).

From these studies, it is clear that indicators, factors and characteristics beyond energy, including environmental impact factors (such as CO_2, pollution, waste), and most significantly regulations and social influences, play a vital role in supporting and assisting decision-making in the retrofit area, as well as illustrating a more accurate understanding of energy efficient retrofits, trade-offs and impacts of a residential buildings lifecycle.

1.3 Retrofit for climate and LCEA

One key element common to all studies is climate. Fay, Trealoar *et al.* (2000) discuss the relevance of temperate areas and the affect this has on the embodied energy, suggesting that the LCEA of dwellings in temperate zones, such as those analysed in this paper, will gain significant operational savings but suffer high-embodied energy. Dong, Kennedy *et al.* (2005) support this in their conclusions, as in the Canadian climate of Toronto, the energy efficiency gain through operation outweighs the large embodied energy components.

Whether embodied energy has a greater impact over operational energy is due to the heating and cooling requirements. A temperate climate has minimal heating and cooling requirements compared to those in more severe climatic zones. Using a breakdown of embodied energy, operational energy and maintenance energy, indicators and cost relevant to the identified climatic zone, energy components can be isolated and analysed against one another and as part of the overall assessment. Dong, Kennedy *et al.* (2005) also conclude that there is a trade-off for energy reduction within the separate phases and that the severity of other impacts should be analysed.

The Australian *Your Home Technical Manual* (Reardon, Milne *et al.*, 2010) categorises Australia's overall climate into eight different climatic zones, from high humidity and warm winters to alpine winters and cooler summers. Australian housing must cater for varied climate conditions dependant on location. Falcone's (2011) research in warmer climates is just one example of the impact climatic zones have on the boundaries and context of retrofitting options.

Without the boundaries set by climate, retrofitting for energy efficiency is extremely unreliable. Therefore climate must be considered as an essential input in LCEA, as the energy efficiency gains are made to improve the energy consumption during the operation and use of a residential building and these are directly linked to climate requirements.

2. The Proposed Framework

The framework of this study intends to support decision-making in retrofitting residential dwellings primarily analysing trade-off impacts from the available retrofit choices, the life cycle cost and the social impacts or influences of these choices. Figure 1 presents the high level framework, showing the relational dependencies of social influences when prioritising retrofitting options, and determining LCEA outcomes.
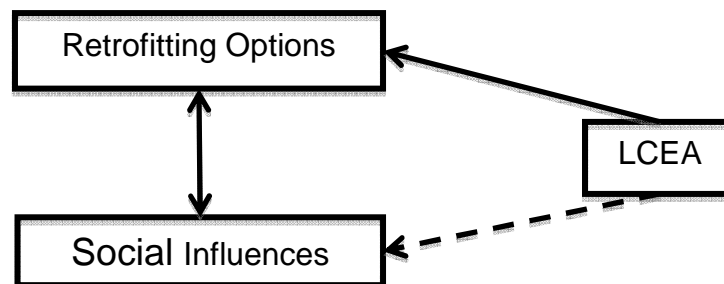

Figure 1 High Level Framework to using LCEA to support Retrofitting choices

Any number of social influences can affect a homeowner or occupier when making choices related to energy within their home. The framework seen in Figure 2 suggests one approach for incorporating these social variables into specific retrofitting choices. It allows social factors to be identified and for physical factors (such as building age and condition) to be excluded as a social variable. This framework enables multiple social variables to be considered while still incorporating house specific details. It allows the LCA process to be seen through these social influences, as well as feed impacts of these choices back into the decision-making process. Further development of this framework would provide a comprehensive understanding of specific social influences; retrofitting options and choices that occur during energy related retrofitting of residential buildings.

2.1 Physical and Social Constraints for Retrofit Options

Every retrofitting scenario is unique and varies based on constraints of each specific dwelling. Building age, condition, location, material make up, and historical significance are some examples of the constraints that determine feasible and available retrofitting choices. Together with the social context of the owners of the dwelling, these variables and constraints determine the priority of retrofitting choices.

2.1.1 Physical Constraints

Different physical constraints influence retrofitting options in various ways; some by eliminating options and others by priority or lack of current techniques. However, physical constraints cannot be changed without some form of retrofit or renovation, and therefore have a significant impact.

The type of building is also a key factor when identifying retrofit choices, and can immediately eliminate options for reasons such as accessibility. Climate and location are

also significant physical factors in building retrofit. Location often incorporates the features of climate as well as building location and orientation (including aspect); housing and population density; historical relevance; and other area constraints. For comprehensive Life Cycle Analysis to be completed, both physical variables and social variables need to be considered. Noting that social variables can be more flexible and vary through means of education, resource availability and incentives
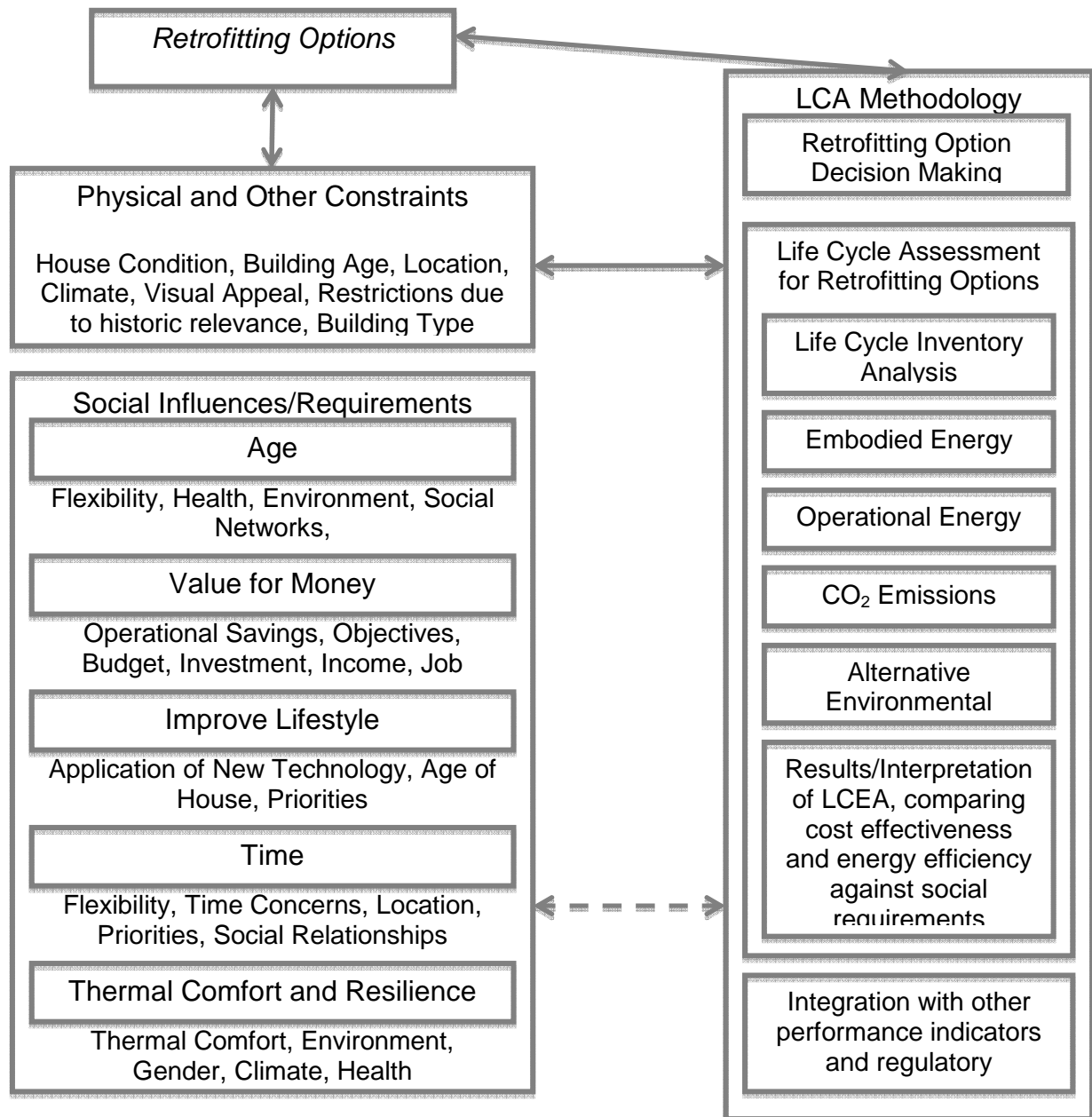
```
┌─────────────────────────┐
│  Retrofitting Options   │
└─────────────────────────┘
```

Physical and Other Constraints

House Condition, Building Age, Location, Climate, Visual Appeal, Restrictions due to historic relevance, Building Type

Social Influences/Requirements

Age

Flexibility, Health, Environment, Social Networks,

Value for Money

Operational Savings, Objectives, Budget, Investment, Income, Job

Improve Lifestyle

Application of New Technology, Age of House, Priorities

Time

Flexibility, Time Concerns, Location, Priorities, Social Relationships

Thermal Comfort and Resilience

Thermal Comfort, Environment, Gender, Climate, Health

LCA Methodology

Retrofitting Option Decision Making

Life Cycle Assessment for Retrofitting Options

Life Cycle Inventory Analysis

Embodied Energy

Operational Energy

CO_2 Emissions

Alternative Environmental

Results/Interpretation of LCEA, comparing cost effectiveness and energy efficiency against social requirements

Integration with other performance indicators and regulatory

Figure 2 Detailed Framework

2.1.2 Social Variables

Social Variables defined as the personal influences on homeowners, such as age, gender, availability, education, any social influences on a homeowner that significantly affects the choices they make regarding their home. For the purpose of this research the identified framework will enable the use of social variables and themes identified in the pilot survey of

10 different homeowners. The purpose of the survey was to identify key social variables that influence each homeowner's choice of retrofitting options. The survey specifically focused on homeowners from two separate age groups, those less than 30 years of age and those over 50 years of age, as they displayed often opposing views. Table 1 displays the extracted themes and key survey results.

2.1.3 Social Variables – Survey Methodology

The survey was conducted by asking a series of closed questions regarding the social status of the participants, before open ending questions sort to establish participant understanding of terminology such as energy efficiency. Beyond this participants were asked to rank preferred retrofitting options and list key arguments to support this ranking. It was clear in the initial discussions, definitions of terminology pose the greatest risk when selecting retrofit options due to the differences in perceived and actual understanding. This survey regulated the variables of terminology, by stipulating each retrofitting option's benefits, impacts on time and specifications. Participants were selected to ensure, they all originated from the same location, and created diversity in age and education, and involvement in energy efficiency practices for the small group of participants. Joint homeowners were considered and interviewed, as individuals to ensure definitions and education factors were not altered by joint ownership influence, or perceived understanding.

The survey presents clear distinctions between younger and older generations and their understanding and perspective of retrofitting and energy efficiency. Younger generations showed a more comprehensive understanding of the diversities within energy efficiencies and options for improvements; whereas, older generations highly regarded maintenance to improve energy use. Younger generations were also more likely to retrofit solely for energy improvements, even replacing working appliances or components; whereas older generations preferred to maintain items for longer and then replace them at the end of their useful life with the most efficient technology. This concept is evident in each age group's readiness to prioritise energy retrofit over other improvements.

Social variables assist in pre-defining the needs of individuals and available retrofit options, prior to completing LCEA. However, they also assist in post-LCEA, where individuals can assess the social influences in conjunction with the whole of life results for any singular retrofit option. The social variables outline the priority of retrofitting options under specific social influences (in this research age was most dominant). This highlights that despite the comprehensive understanding of the whole of life efficiencies LCEA demonstrates, it is overshadowed by individual preference dominated by their social influences, outcomes and objectives.

2.2 Retrofitting Options

Varying age groups and building constraints determine various retrofitting options. The retrofitting options considered for this research can be seen in Table 1 and are prioritised by the age of households, specifically the two age groups that identified to have the most common trends. Different aged households have diverse priorities and these priorities

determine the best retrofitting choices for each social perspective. These are the perspectives that will be tested through LCEA to determine if the social requirements of either group to achieve greater energy improvements.

Table 1 Modelling Parameters Used in Accurate or LCADesign Software and Priority of Age Group

Product		Modelled as	Priority <30	Priority >50
			(6 being top priority, 0 being least priority)	
Replace Single Glazing with Double Glazing Windows	Low U-Value, Mid range Solar Heat Gain Coefficient, Season Specific Shading	Modelled as Double Glazing with a 6mm air gap between high performance glasses.	4	1
Installing Wall Insulation	Achieve an R-value of 2.8	Modelled with an R-value of greater than 3.5 regardless of material selection/material type	5	0
Installing Ceiling and Wall Insulation	Achieve an R-value of 2.8 for walls and 4.1 for ceiling	Modelled with an R-value of greater than 3.5 regardless of material selection/material type	5	0
Installing Floor Insulation	Achieve an R-value of 1.25 (expect for slabs on ground)	Modelled as plastic sheeting between floor slab and ground; or in suspended floor with R-value greater than 3.5 regardless of material selection/type	5	0
Installation of various Air-Sealing techniques	Installation of foam/rubber compression material, draft protection on doors, self closing doors, exhaust fans fittings with a flap/dampener	Not modelled; taken from literature or negligible	2	4
Installation of various Shading Devices	Add shading either devices or deciduous trees to prevent summer sun and aid winter light	Not Modelled	1	3
Installation of Skylights to reduce artificial lighting	Low U-Value, Mid range Solar Heat Gain Coefficient, Season Specific Shading	Modelled as Double Glazing with a 6mm air gap between high performance glasses.	0	0
Replacement of Appliances to all 3.5 stars or above		Modelled as appliances with 3.5 star rating or where no half star available 4 star rating	0	5
Replace solar heating for water		Modelled as single solar panel, with 0.75 efficiency	0	2

2.2.1 LCEA Decision Support Tool

LCEA can be used as a decision support tool when comparing available retrofitting options. The most significant of advantages is ability to use LCEA to give a whole of life understanding of energy uses and demands. This is the process that software packages will be used to calculate in order to determine embodied and operational energy used over the lifetime of a case study.

2.2.2 Embodied Energy – LCADesign

For the calculation of embodied energy LCADesign and Building Information Models were used to assess the total embodied energy of the base case studies as well as retrofitting scenarios. LCADesign is a software tool used to analyse and assess the embodied energy of a building. By using Building Information Models, LCADesign can comprehensively assess the embodied energy of the components used to construct a building. Each material can be 'tagged', identifying it from the Australian specific Life Cycle Inventory. Analysis for a single dwelling can be run with multiple inventory models, allowing comparison between retrofit options.

2.2.3 Operational Energy – AccuRate Sustainability

For the calculation of Operational Energy, AccuRate Sustainability was used. AccuRate Sustainability is currently one of the software products recommended by Australian Government when assessing a dwelling's star rating. AccuRate Sustainability predicts the required operational energy consumption for one year given building parameters. Building parameters required include occupancy, room size, volume and orientation, hot water heating, lighting and water sources. AccuRate Sustainability provides star rating indicators, energy consumption in Mega Joules/area, as well as water heating energy and water consumption assessment.

Other indicators can be assessed from both software packages, such as water usage, gas usage, as well as other environmental factors, including CO_2 and Greenhouse gas emissions. For the purpose of LCEA, energy is the primary indicator, however there are a number of alternative software packages that take these environmental factors into consideration beyond LCADesign and AccuRate Sustainability, but are beyond the bounds of this research.

2.3 Findings and Discussion

2.3.1 LCEA and Social Influences

In the case studies tested, the operational energy decrease appears to coincide with embodied energy increase, with the introduction of new materials. Embodied energy does not accurately reflect the reasons to retrofit, objectives or retrofitting priorities of homeowners. In understanding the trade-off between this increase and the operational energy benefit to be gained we can begin to deduct the social impacts of these results.

Younger generations' choices are fuelled by their objectives to reduce their environmental footprint and consumption, something not reflected in their reasoning when choosing a retrofit option. When prioritizing the available retrofitting options, younger people chose options that reflected their objectives and offered large operational energy savings, with high embodied energy costs. These choices, however, resulted in a life cycle energy reduction, improving the energy efficiency of their home. Despite younger people's comments regarding limited budgets and significant time constraints, they prioritised retrofitting choices that met their objectives before other choices.

Older generations' reasons to retrofit, objectives and retrofitting priorities were very much in line with one another, indicating a clear understanding of their goals when it comes to retrofitting their homes. Their choices reflected their time and budget constraints and their understanding of the impact of retrofitting on their daily lives. Unlike younger people, their choices did not have large operational savings, or high embodied energy, instead they offered a more diverse consumption reduction, indicating that a LCEA cannot assess the total environmental impact of their choices.

It is clear that for the survey group in this study that their retrofitting priorities were based very much on their overall objectives for their homes rather than their reasoning to retrofit, these objectives reflected high-level thinking and goals, as opposed to lower level outcomes.

The younger age group chose better retrofitting options in terms of LCEA, as they opted for retrofitting priorities, which significantly reduced their energy consumption. This suggests that in isolation LCEA shows younger generations make more effective choices, however does not fully consider all environmental impacts that are affected by these choices. Older generations choices reflect a broader perspective on energy efficiency and environmental sustainability that LCEA does not adequately measure or account for in this research.

LCEA supports decision-making with respect to energy consumption, and this whole of life view is crucial in understanding what energy trade-offs are made with each retrofitting decision. Assessing the social influences on retrofitting options through LCEA gives a clear understanding that most retrofitting options will improve the life cycle energy of a home. However, it does not fully assess the environmental impacts beyond energy demand, and this can be seen as one of its greatest limitations.

2.3.2 Limitations

There are a number of limitations to this research. The pilot survey conducted was limited to a specific climate zone, and sought out particular participants, those in a position to retrofit. Due to the small sample size, it is hard to ascertain key trends beyond the two age groups listed and their key objectives and retrofitting priorities. Presenting the results on the clearest trends in data has mitigated this limitation.

The Life Cycle Inventories used, were based on assumptions from software developers. The software programs offer only a single Life Cycle Inventory (LCADesign) and have their own methodologies and frameworks for the calculations used to simulate energy performance.

The development of Australian Life Cycle Inventory Data is limited by the research available for each individual product and, therefore, retrofitting options such as appliances cannot be fully assessed via simulation.

Conclusions

The framework presented in this research has highlighted a number of areas for further development and research to complete a comprehensive understanding of the social influences that affect retrofitting options.

Operational energy is the largest consumer in Life Cycle Energy accounting for approximately 80% of the total Life Cycle Energy demand. Reducing this operational energy is the largest trade-off when making retrofitting decisions, regardless of social influences present. There are key limitations and gaps in the current research regarding common household appliances and how they can be used to reduce energy. Capturing these reductions in energy, from appliances, such as water heaters, dishwashers, and TV's, can help to assess the impact of purchasing higher rated appliances. Social consumerism is already prominent in many appliances, with star rating systems in place. However, there is a lack of integration between these star ratings and the total impact on the life cycle energy of a residential building.

Similarly, little is understood about the impact of appliances on embodied energy of a residential building, despite an understanding of the impact of these individual products. The results presented indicate, even with large embodied energy increases from the introduction of further materials, the operational energy savings is decreased significantly, often outweighing the impact of embodied energy on the total life cycle. This currently is not the case for appliances, or solar heating.

Social Influences pose the biggest threat to reducing residential buildings energy impacts. Social Influences affect not only the choices homeowners make when retrofitting, but also, how they make these choices. The survey completed in this research is applicable to many retrofitting scenarios and further analysis from the data available could present further trends in this particular set of scenarios. Understanding the motivation behind the choices made by various social groups allows a more comprehensive understanding of the way policy, rebates and enticements can be introduced to produce a more energy conscious and more energy efficient homeowner.

Life Cycle Energy Analysis allows the homeowner to understand the whole of life impact of their choices with respect to energy and is crucial to being able to better predict home energy consumption and better improve energy choices for new homes, as well as retrofitting existing homes. Trends in Australia suggest comprehensive research into the social influences of homeowners and their motivations and understanding of energy retrofit.

Future Research

Life Cycle Energy Analysis is a comprehensive tool in understanding a whole of life scenario in residential dwellings in Australia. It allows homeowners the ability to assess the long-term and short-term energy benefits of any retrofitting scenario. Further studies into how social variables affect the understanding and decision making of homeowners is necessary in order to fully understand the energy needs in Australia's existing housing stock. A thorough knowledge of Australia's average dwelling, average occupancy and social attitudes will critically influence energy outcomes in all aspects of the residential sector, and is vital in ensuring our energy demand

References

Australia/New Zealand Standard, 1998, *Environmental management - Life Cycle Assessment - Principles and framework,* ISO 14040:1998, accessed 28 February 2012,

Australian Building Codes Board 2011, accessed 28 April 2012. http://www.abcb.gov.au/

Department of the Environment 2008, *Energy Use in the Australian Residential Sector 1986-2020,* Cat no. 978-1-921298-14-1, Department of the Environment, Water, Heritage and the Arts, Canberra.

Dong, Kennedy, et al. 2005, "Comparing life cycle implications of building retrofit and replacement options", *Canadian Journal of Civil Engineering,* Vol.32, 6, pp. 1051-1063.

Falcone 2011, *Energy Retrofit of Residential Buildings in a Hot Climate*, Doctoral School in Structural Engineering Salerno, Department of Civil Engineering: University of, Ponte don Melillo.

Fay, Treloar, et al. 2000, "Life-cycle energy analysis of buildings; A case study", *Building Research and Information,* Vol.28, 31-31.

Hogan 2011, "A Design Approach to Achieve the Passive House Standard in a Home", MArch, Department of Architecture, University of Oregon, (UOO).

Morrissey and Horne 2011, "Life cycle cost implications of energy efficiency measures in new residential buildings", *Energy and Buildings,* Vol.43, 915-924.

Ramesh, Prakash, et al. 2010, "Life cycle energy analysis of buildings: An overview", *Energy and Buildings,* Vol.42, 1592-1600.

Reardon, Milne, et al. 2010, *Your Home Technical Manual*, Fourth Edition, Department of Climate Change and Energy Efficiency, Efficiency, Department of Climate Change and Energy, Canberra.

Yohanis and Norton 2002, "Life-cycle operational and embodied energy for a generic single storey office building in the UK", *Energy,* Vol.27, 77-92.