Integrating Built Heritage and Sustainable Development: Can Assessment Tools be Used to Understand the Environmental Performance of Existing Buildings with Heritage Significance?

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Key words: heritage buildings, environmental performance, life cycle assessment, Australia.

SUMMARY

Attention is turning to the long-term management of the existing building stock, and in particular the adaptation of existing buildings, to achieve more efficient use of resources, reduce energy consumption and greenhouse gas emissions (CSIRO, undated; Kohler and Hasser, 2002; Itard and Klunder, 2007; Empty Homes Agency, 2008; Thomsen and van der Flier, 2009). It is asserted that adaptation of existing buildings can play a key role in sustainable development (Wood, 2005; Douglas, 2006; Kohler and Yang, 2007; Bullen, 2009; Wilkinson, 2009).

Of the 8.3 million dwellings in Australia, 57% are 20+ years old (ABS, 2009; Australian Greenhouse Office, 2007). However, little is known about the performance of the older building stock. Furthermore, many existing buildings are heritage registered, with 14,148 historic-listed places at the state and territory level, and more than 76,000 individual historic places and 1,770 historic heritage areas at the local level (DEWHA, 2006).

This paper reports on a recent Australian study to assess the operational and embodied energy of a range of existing buildings of varying construction dating from c.1880s to 2000. The operational loads for each building were modelled using *AccuRate*, a second generation housing simulation software tool used to assess the thermal performance of dwellings, and integrated with the life cycle model constructed in *SimaPro* life cycle assessment software. The findings from the operational and embodied energy for a selection of representative case studies of residential buildings in Victoria challenge the common perception that heritage buildings always perform poorly in terms of energy performance. This empirical research indicates that using current simulation tools, the performance of some older buildings is comparable or better than new buildings in some aspects (e.g. cooling loads). When embodied energy and energy consumed in materials replacement is considered, existing buildings can offer advantages over new buildings in terms of life cycle environmental performance.

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1. BACKGROUND –THE CHALLENGE

The adoption of sustainability has become the principal goal in many countries, including Australia, since the publication of Brundtland Report *Our Common Future* in 1987 (Brundtland and World Commission on Environment and Development, 1987). The Brundtland Report seeks to reconcile economic development with environmental and social concerns.

The built environment offers considerable opportunities for reducing environmental impacts (Kohler and Hassler, 2002); (Urge-Vorsatz *et al.*, 2007). It is widely recognized that the building sector is a major consumer of resources: within OECD countries, including Australia, buildings consume 32% of the world's resources, and 40% of the energy used in developed countries is related to buildings, predominantly for heating and cooling but also for the production of materials used in construction (OECD, 2003).

For the most part, the discussion about sustainability and buildings concentrates on new-build, with relatively little consideration given to the adaptation of existing buildings as an alternative and sustainable option. However, attention is turning to the long-term management of the existing building stock as an effective strategy for sustainability (Kohler and Yang, 2007); (Wood, 2005); (Wilkinson, 2009); (Thomsen and van der Flier, 2009). In particular, studies are increasingly focusing on the adaptation of existing buildings to achieve more efficient use of resources, reduce energy consumption and greenhouse gas emissions (CSIRO, undated); (Itard and Klunder, 2007); (Itard, 2009).The adaptation of existing buildings can play a key role in sustainable development (Bullen, 2009); (Douglas, 2006); (Kohler and Yang, 2007).

New buildings are added to the building stock at a rate of between 1-5% each year (Wilkinson, 2009), and account for a relatively small proportion of the building stock in Australia. There are 8.3 million dwellings in Australia, of which 57% are 20+ years old (ABS, 2009); (Australian Greenhouse Office, 2007). In Victoria, existing older dwellings represent more than 95 per cent of the housing stock (Building Commission, 2008). The existing building stock has the greatest potential to lower the environmental impacts significantly in the next 20 to 30 years (Rovers, 2004). The adaptation of existing buildings also offers social and economic benefits (Rypkema, 2009); (Wilkinson and Reed, 2008); (Urge-Vorsatz *et al*, 2007).

Many existing buildings are heritage registered: there are 14,148 historic-listed places at the state and territory level, and more than 76,000 individual historic places and 1,770 historic heritage areas at the local level (DEWHA, 2006). Although buildings of cultural heritage significance are quantitatively a small proportion of the building stock, they are, nevertheless, significant in terms of their contribution to the broader aims of sustainable development – and provide benefits well beyond the value of saved energy. Indirect (ancillary) benefits include economic and social benefits such as contributing to local identity, quality of life, employment, new business opportunities and tourism (Department of the Environment and Heritage, 2004).

The next section of the paper provides the introduction and the context for this study. This is followed by the aims and an explanation of the method used for this research. Selected case studies are described in the following section. The findings and a discussion of the findings culminates in the conclusions.

2. INTRODUCTION

The State of Victoria is located in south-eastern Australia, covers an area of 228,178km^2 (88,100 square miles) and is home to a population of 5.4 million, of which 4 million live in Melbourne, the state capital and the second largest city in Australia after Sydney (ABS, 2009; The Age, 2009). Melbourne was first settled in 1835 and expanded rapidly following the discovery of gold in Victoria in 1851. In the ensuing building boom, Melbourne quickly developed into a thriving administrative, financial and commercial centre. The expansion continued until 1891, when growth abruptly stalled due to an economic downturn, and did not resume until after the First World War. Melbourne developed rapidly after the Second World War with a period of increased prosperity and the influx of migrants from Europe and Asia. The profile of the existing building stock closely reflects the periods of historic growth.

Environmental performance in buildings has become increasingly important in recent years. In an effort to improve energy efficiency, the Australian Government and Australian Building Codes Board (ABCB) have introduced minimum requirements through the Building Code of Australia (BCA) which mandate energy efficiency requirements for all buildings, including the refurbishment, alteration or extension to existing buildings (ABCB, 2009). The BCA requires houses and apartments to achieve a rating equivalent to 5 Stars under the Nationwide Housing Energy Rating Scheme (NatHERS), focusing on the energy efficiency of the thermal envelope. Heritage registered buildings are not exempt from this requirement. However, there is some discretion to allow partial compliance for smaller extensions or extensive alterations where the requirement is impractical. Victoria was the first state to introduce 5 Star compulsory energy efficiency standards for new houses (Building Commission, 2008).

Previous research has tended to focus on operational energy impacts and the reduction of energy used during occupation (Vacca *et al.*, 2009). Several studies have investigated the environmental performance of existing buildings, including the influence of occupants' behaviours on energy efficiency (Fay *et al*, 2000); (Bell and Lowe, 2000). The impacts of refurbishment of existing buildings are considered in comparison to demolition and redevelopment (Itard and Klunder, 2007). Empty Homes Agency (2008) compared CO_2 emissions in building new homes and refurbishing older properties in the UK. This study revealed that new homes had higher embodied energy costs. Although well-insulated new homes eventually make up for their high embodied energy costs through lower operational CO_2, it takes several decades - in most cases more than 50 years. Yet little work has been carried out into the embodied and operational energy involved in adapting existing buildings and the environmental impacts in comparison to new build, and the relative importance of each.

Embodied energy is the energy used for constructing dwellings and associated maintenance over a period of time. The neglect of embodied energy and its associated environmental impacts is misleading, as it overestimates the energy and CO_2 savings new homes can make. At the same time, it underrates the potential of existing homes to help reduce energy use and cut emissions.

As operational energy exceeds embodied energy in the total energy of a building over its life span, it is argued that the environmental benefits of redevelopment are greater than extending the life of older 'inefficient' buildings through refurbishment (Boardman, 2007). However, wholesale destruction of large numbers of older buildings is a waste of physical resources, it is more expensive than refurbishment, and has undesirable social impacts including displacement of communities, erosion of social capital, reduction in affordable housing, as well as avoidable loss of heritage (Lowe, 2007).

A number of studies indicate that for materials, emissions and waste the environmental impact of life cycle extension through refurbishment is less than demolition and new construction (Bell and Lowe, 2000); (Itard and Klunder, 2007); (Braganca and Mateus, 2008); (Empty Homes Agency, 2008); (Itard, 2009); (Meijer et al., 2009). Retaining and upgrading existing buildings is more efficient; not only can operational performance be improved at less cost than demolition and new construction, existing infrastructure can be utilised, and significant hidden 'embodied' emissions from construction, materials, and waste can be avoided (Pearce, 1996); (Bell and Lowe, 2000); (Lowe, 2007); (English Heritage, 2007); (Building Research Establishment, 2009).

Taking into account the energy embodied in an existing building, it can take several decades before energy savings are realised by building new rather than renovating an existing building (CSIRO, 2000); (Killip, 2006 cited in Boardman, 2007). According to Pearce (2003), there can be no guarantee that the resource use and emissions from reduced new build is greater than the environmental impacts of increased conversion and repair, although it seems likely.

Although there is no consensus over the interplay between operational energy and embodied energy, it is acknowledged that as operational energy is reduced, the embodied energy component is likely to become more significant in the life cycle energy analysis of buildings (Fay et al., 2000);(Boardman, 2007); (Itard, 2009).

The role of existing built stock with regard to environmental sustainability cannot be ignored. The next section of the paper provides the aim and scope of this research.

3. ASSESSING PERFORMANCE OF EXISTING BUILDINGS

This paper reports only the first phase of a broader research program. This section presents the aims of the project, the method used for this research and the tools used to analyse the performance of existing buildings.

3.1 Aims of the project

There are currently 2.1 million dwellings in Victoria (ABS, 2009). Many of these buildings were constructed prior to the introduction of regulations to improve energy efficiency and without consideration of their environmental impact. These existing homes are likely to remain in use for the next 50-80 years – those built between 1994 and 2004 are estimated to have an energy rating of around 2 stars, and those built prior to 1994 an energy rating somewhat less than this (Department of Sustainability and Environment, 2006). Many older buildings are perceived as being in poor condition and operating very inefficiently –with high energy consumption (Pearce, 2003); (Wilkinson and Reed, 2008).

This research was commissioned by the Heritage Council of Victoria in association with the Building Commission of Victoria, the Department of Planning and Community Development, the Office of the Victorian Government Architect (Department of Premier and Cabinet), and the Department of Sustainability and Environment, Victoria.

The broader objectives of the project are to:

–identify the quantum of embodied energy contained in typical building types of heritage value;

–inform the public of the ways in which the retention and adaptation of existing buildings and those with cultural heritage significance can contribute to environmental sustainability;

–provide information that will allow building designers, specifiers and owners to make more informed judgments about the sustainability legislative requirements for existing buildings;

–provide evidence that building surveyors and other regulators can use when considering Alternative Solutions to the Deemed-to-Satisfy Provisions of the Building Code of Australia;

–provide comparison between different industry standard sustainability analysis and modelling methodologies as applied to heritage buildings;

–encourage imaginative, performance based design solutions to improve the environmental sustainability of the existing building stock.

The immediate aim was to gain a better understanding of the quantum of embodied energy in typical buildings of heritage value and energy needed to operate these buildings.

As this paper concentrates on the initial findings of the study, the research undertaken for the initial phase completed in late 2009 is reported. Eight buildings are selected as case studies, and reported in this paper. Complete analysis is expected to be completed in the first quarter of 2010.

3.2 Method

The Centre for Design, RMIT University was commissioned to undertake the modelling and data analysis for the selected case study buildings. Heritage Victoria has maintained an active role in the project, including historical research of databases and documentary records to identify suitable building case studies, providing building plans and utility bills (with the consent of the owners), and survey of selected buildings to verify the accuracy of plans.

The research involved the following steps:

–Undertaking a literature search of current research on the embodied energy and sustainable adaptation of heritage and existing buildings;

–Identifying commonly recognised existing building types, some with heritage significance. Archetypes were identified and, using the Victorian Heritage Register, local government Heritage Overlay and Victorian State Government portfolio of buildings, a smaller number of representative case studies were selected for in-depth analysis.;

–Assessing operational energy in heritage buildings using a variety of modelling and first principle design methodologies;

–Assessing the embodied energy of the selected heritage and existing buildings and a comparison with a modern equivalent;

–Assessing the impact on energy usage for various interventions such as adding insulation, refurbishing existing windows, installing secondary or double glazing installing window and floor coverings, low-energy light fittings and energy-efficient appliances including heating, cooling and hot water systems;

–Identifying and reviewing a range of suitable design solutions that can be used to achieve acceptable levels of sustainability in heritage buildings that satisfies current building legislation requirements.

The next section focuses on the tools available to analyse the environmental performance of buildings.

3.3 Tools used to analyse environmental performance

As indicated in previous sections of the paper, both operational and embodied energy was modelled. Also, as previously indicated, Australia has mandated requirements for the thermal performance of the building envelope. The BCA has set out preferred software for use to achieve the required thermal performance. Modelling of operational energy usage of the case study buildings was done using *AccuRate*, a second generation simulation package used to rate the thermal and energy performance of Australian houses in climate zones ranging from alpine to tropical. The software is the reference tool for the Nationwide House Energy Rating

Scheme (NatHERS), and provides the benchmark for accrediting other HERS software for use with the Building Code of Australia (BCA) requirements.

The embodied energy component of the Life Cycle Analysis (LCA) was carried out using *SimaPro* software. *SimaPro* is a LCA tool for assessing the environmental effects of buildings in terms of material use, energy consumption, and environmental impacts. The following indicators were selected for measuring environmental impacts: climate change, land use, water use, smog, eutrophication, acidification, ecotoxicity, and human toxicity. Life Cycle Inventory modelling was carried out for the selected buildings (including cradle-to-gate manufacturing, transport, construction processes, use (combined with operational energy aspects), maintenance and replacements).

For LCA purposes, the functional unit for this research is defined as the environmental assessment of an existing building with heritage significance over a fifty, and one hundred year life span including embodied, operational and end of life management of materials. The functional unit is important as the lifespan determines the range of distribution of embodied energy. This analysis is based on a building life span of one hundred years. This is longer than a typical assumed lifespan - and many residential buildings are replaced within that time – however, it is assumed that heritage buildings will be retained.

The operational energy in this study is the primary energy use, not the delivered energy that the owners or tenants pay for. The primary energy use takes into account the entire energy chain, including power generation at power stations and supply to households. Primary energy may be 3 or 4 times greater than delivered energy.

The analysis of performance integrates the operational heating and cooling load performance of each building with the energy flows associated with embodied and replacement energy of materials, and building construction processes. The energy model for the building construction process was constructed based on the predominant material component (brick veneer, weatherboard, timber and solid brick) of the building. The operational loads for each building were modelled in *AccuRate* and further integrated with the life cycle model constructed in *SimaPro*.

Having outlined the approach for the research, the next section focuses on the building case studies.

4 BUILDING CASE STUDIES

This section explains why a case study approach was deemed to be the best approach for this research. It also presents the results for operational and embodied energy using *AccuRate* and *SimaPro* modelling software.

To meet the overarching and immediate aims of the research case studies offer the best approach. Case studies provide the opportunity to gather rich data for not just understanding the quantum of operational and embodied energy and water, but also identify opportunities to meet legislative and regulatory requirements. Since a range of buildings are selected as case studies, there are possibilities to test the application of a range of innovative, performance based solutions to improve the environmental sustainability of the building stock. Although there was a need for a range of building stock to be represented, budgetary constraints restricted the number of cases studies for in-depth analysis. As indicated earlier, this research is still ongoing, hence, this paper focuses only on the energy analysis of eight residential buildings.

A reference building also needed to be selected as a basis for comparison. The reference building chosen was one that met the minimum regulatory energy requirements as outlined in the BCA.

In choosing the case study buildings, the following were taken into consideration:

- a range of building archetypes to represent not just Victorian but also buildings nationally
- representation of the architectural design, characteristics and form of construction
- different categories of heritage significance (ie local, state and individual building or area designation)
- condition of external fabric of the buildings
- representation of more than one climatic zone as determined by *AccuRate*
- retention of the original form of the building, ie the building has had little modification since its original construction.

The case study buildings are single family dwellings ranging in date from 1880s to 2000. Building case studies were selected from this period to include a cross-section of building archetypes commonly found throughout Victoria, and widely recognized in most states and territories in Australia. The buildings selected are representative of the housing stock in terms of architectural design, characteristics and construction, and therefore suitable for inclusion in the study.

The external fabric of all the buildings was in good condition. In identifying suitable case studies, an attempt was made to find examples that were intact, without significant alterations. However, unaltered examples are rare and the majority of buildings in the study have been altered in some form, or even extended. Although Google Maps Street View and Google Earth proved useful, due to incomplete coverage the existence of adaptations was not evident in some instances until the site inspection was carried out. Where major alterations had been carried out, these were taken into account in the modelling.

The case study buildings were selected from various locations around Victoria. *AccuRate* categorizes Australia into 69 different climate zones. The case study buildings are within 3 different zones. The residential buildings range in date from 1880s to 2000, with examples selected at approximate 20 year intervals. Six of the eight buildings selected have recognized heritage significance, being listed individually either at the state level (on the Victorian

Heritage Register) or at local level (on the Heritage Overlay in the municipal Planning Scheme). Two of the buildings are included within a locally designated heritage precinct.

The case study buildings were selected to reflect a range of different architectural styles and construction types as shown in Table 1.

No	Building description	Date	Construction	Location (Local Government Authority LGA)	Heritage significance: State/Local
1	Free standing 4 bedroom outer suburb house	2000	Brick veneer walls Concrete tiled roof Concrete floor	City of Bundoora	N/A
2	Two storey single fronted mid-late Victorian period terraced house	1880s	Solid brick walls Galvanised metal roof Timber floor	Melbourne City	State Victorian Heritage Register
3	Free standing single storey double fronted Edwardian period house	1911	Timber (weatherboard) walls Metal roof Timber floor	City of Geelong	Local Heritage Precinct
4	Free standing single storey house (State Savings Bank of Victoria Garden Bungalow Design T18)	1926-40	Timber (weatherboard) walls Metal roof Timber floor	City of Geelong	Local Heritage Precinct
5	Free standing double fronted Interwar period house	1932-1933	Timber weatherboard walls Terracotta tiled roof Timber floor	City of Geelong	Local Heritage Overlay
6	Free standing single storey triple fronted post war house	1950s	Brick veneer walls Concrete tiled roof Timber floor	City of Ballarat	Local Heritage Overlay
7	Free standing single storey 3 bedroom middle suburb house	1972	Brick veneer walls Concrete tiled roof Concrete floor	City of Moonee Valley	N/A
8	Apartment in residential block	1935/37	Brick rendered walls Tiled roof Concrete floor	City of Melbourne VIC	Local Heritage Precinct

Table 1 Building case studies: characteristics

4.1 The benchmark

The reference building (Building no. 1) dates from 2000, and meets the Victorian government's requirement for a minimum 5 Stars for any new residential building. This modern 2-storey brick veneer building has minimum insulation requirements in accordance with the Building Code Australia (BCA). Insulation is provided within the external and internal walls, and the roof in order to meet the minimum Star Rating requirement. There is no external shading to the windows except for the standard blinds installed to the inside face of the windows. A standard eaves (depth 600mm) exists around the building. An image of the building is shown in Figure 1.

Figure 1 The benchmark. Building no. 1: a modern 5 Star rated house.

4.2 *AccuRate* modelling

The results of the *AccuRate* modelling for understanding the building performance are provided. The performance of the older buildings (Building nos. 2 to 8), as simulated by the *AccuRate* software, is lower, as the ratings range between 0.9 Stars to 3.6 Stars.

The common perception is that old buildings perform badly in terms of energy efficiency. However, the results as demonstrated by *AccuRate* indicate that the various buildings perform differently due to different variables. Building nos. 3, 4 and 5 are located in Geelong; Buildings 3 and 4 are of similar construction i.e. timber frame with weatherboard cladding and metal roof. Buildings 3 and 5 achieve 1.9 and 2.3 Stars respectively. Building no. 4 has a rating of 0.9 Stars. Building no. 4 has a higher heating load than Building nos. 3 and 5, but Building no. 5 has the higher cooling load. Building no. 3 has lower heating and cooling loads than Buildings 4 and 5; this may be attributed to the presence of external shading and high ceiling height in Building no. 3. Although Building No. 3 is North and West facing it has external verandahs and shading (Figure 2). The internal spaces of Building no. 4 are cooler compared to Building nos. 3 and 5, therefore, requiring less cooling loads. Building nos. 3 and 5 face East and West. Building no. 5 has no shading to the main living area. There are also variations in the insulation in external walls and roof.

Building numbers 6 and 7 perform reasonably well with 3.6 and 3.4 Stars respectively. These buildings have similar construction (brick veneer external walls, and tiled roof) with insulation to the external walls and roof space only. Building number 6 is located in the climatically colder area of Ballarat (inland location in regional Victoria) than Building number 7 (Melbourne inner north west), which could explain the reason for a much higher heating load and lower cooling load requirement for the building to maintain acceptable internal comfort for the users.

Figure 2 Building no. 3: heritage building with a Star Rating of 2.3

Building nos. 2 and 8 achieve slightly above average ratings of 2.6 and 2.8 Stars. Building no. 2 is a terraced house and Building no. 8 is a ground floor apartment. These buildings have thick masonry walls, and only Building no. 2 has insulation – in the roof space only. These buildings have lower heating and cooling loads, and their performance may be due to minimum exposure to sunlight on the external walls due to the presence of adjacent buildings, and smaller and fewer window openings.

4.3 LCA and LCI modelling

A Life Cycle Assessment (LCA) offers a systematic and comprehensive approach to analyse the energy requirements and environmental impact of a building. The analysis includes the energy required to construct the building, the energy used during occupancy and the energy used to maintain/renovate the building.

A quantity surveyor was engaged to calculate materials quantities from the drawings for each house to produce the Life Cycle Inventory (LCI). The LCI is an estimate based on standard materials and construction as the actual houses included in the study vary in date, and it is difficult to account for the energy required to manufacture building materials over a century or more ago. The buildings may therefore have higher or lower embodied energy costs than the figures quoted in this study. However, the method used for calculating the materials and quantities was the same for all of the case studies.

No	Building description	Orientation	Building Area in m^2	Heating $MJ/m^2.yr$	Cooling $MJ/m^2.yr$	Total Energy $MJ/m^2.yr$	Star Rating
1	Free standing 4 bedroom outer suburb house	East	218	117	45	162	5.1 Stars
2	Two storey single fronted mid-late Victorian period terraced house	West	125	296	18	314	2.6 Stars
3	Free standing single storey double fronted Edwardian period house	West	220	404	18	422	2.3 Stars
4	Free standing single storey house (State Savings Bank of Victoria)	North	114	655	46	701	0.9 Stars
5	Free standing double fronted Interwar period house	East	280	414	55	469	1.9 Stars
6	Free standing single storey triple fronted post war house	South	154	351	27	378	3.6 Stars
7	Free standing single storey 3 bedroom middle suburb house	East	171	257	36	293	3.4 Stars
8	Apartment in residential block	North-east	92	290	6	296	2.8 Stars

Table 2 Comparison of operational energy and Star Rating

A dynamic life cycle model with three components (embodied energy in materials, material replacement energy, and primary supply energy for heating and cooling loads) was constructed for the eight Victorian buildings. The integration of the four components to the model highlights the ‘dynamic’ aspect of the LCA model, which is illustrated in Figure 3 as an Integrated Process Model. The iterative material selection model evaluates the variation in energy and emissions results in comparison to the baseline scenario, as a function of using increasingly energy efficient materials. The dynamic LCA investigates the potential tradeoffs involved in the different life cycle stages and the net energy and environmental benefits realised.

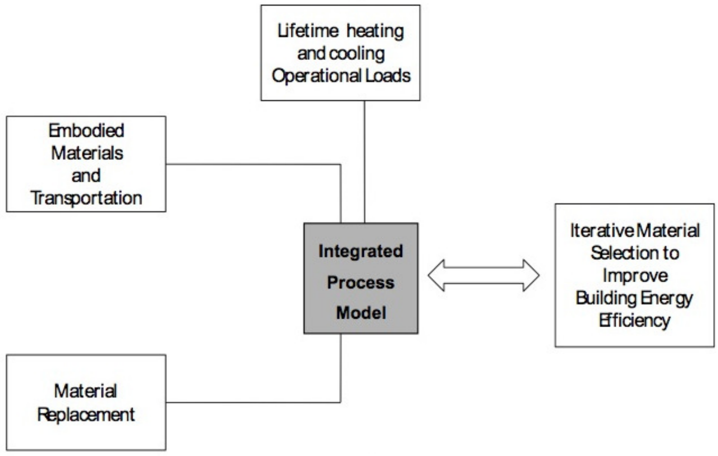

Figure 3 The framework of the dynamic LCA model

As this study focuses exclusively on the life cycle primary energy consumption and CO_2 emissions, it was essential to understand this in the Australian context. The Australian grid characteristics such as the energy production efficiency and carbon intensity were used to analyse the primary energy consumption and CO_2 emissions associated with the material and energy flows during the building life cycle[i].

In this study the materials in the different dwellings were replaced based on the lifetimes adopted from the National Association of Home Builders (NAHB) report[ii] and subsequently integrated with the life cycle model.

The next section provides an analysis of the findings of the study.

5 INITIAL FINDINGS

For ease of understanding and communication, the findings have been presented as primary energy consumption.

5.1 Primary energy consumption

The total primary energy consumption for the eight residential buildings is considered in this section. The total life cycle primary energy consumption includes energy flows associated with the following stages:

- Initial embodied energy
- Replacement of materials (e.g. in maintenance, renovation)
- Construction processes
- Heating load
- Cooling load

The analysis integrates the operational heating and cooling load performance of the building with the energy flows associated with embodied and replacement energy of materials, and building construction processes. The energy model for the building construction processes is based on the predominant material (brick veneer, weatherboard, timber and solid brick) for each building. The operational loads for each building were modelled in *AccuRate* and further integrated with the life cycle model constructed in *SimaPro*.

Figure 4 presents the life cycle primary energy consumption for the eight case studies.

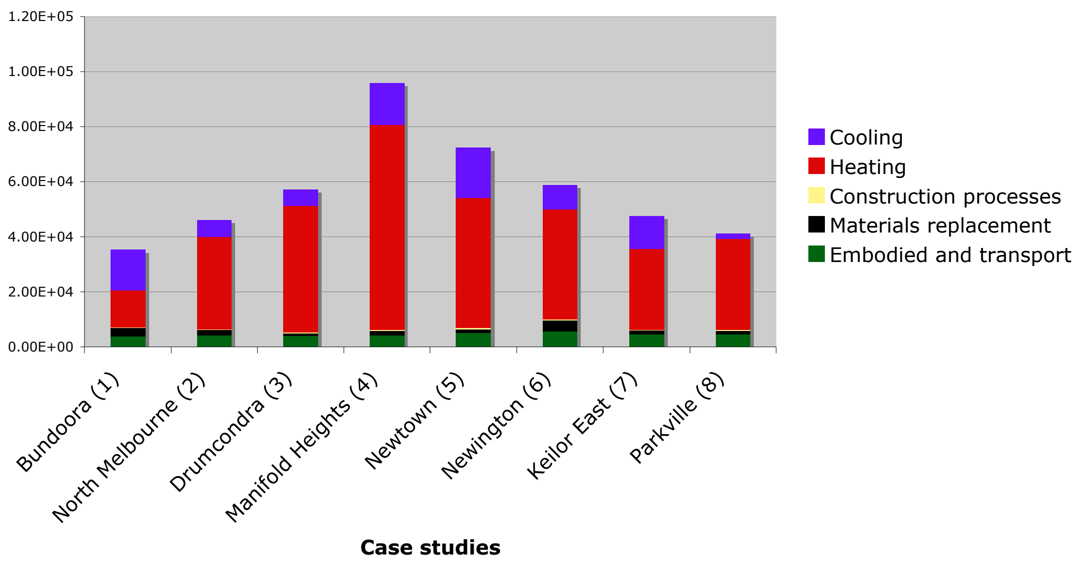

Figure 4 Lifecycle primary energy supply for embodied materials, material replacement and primary energy supply for heating and cooling loads

The embodied energy component is included in the primary energy consumption. Embodied energy is defined as 'the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions' (CSIRO, 2000). For this study, the embodied energy estimate also includes recurrent energy i.e. the energy added through goods and services used in maintenance and refurbishment over the life span of the building (Fay et al., 2000). These are modelled by assuming typical replacement rates for elements in the building (see end note 2). The energy associated with construction processes is also included.

The embodied energy analysis for each building was calculated from the quantities of the materials used in construction derived from the drawings and measurements obtained on site. The embodied energy intensity values for the materials and components were obtained from inventories.

Building no. 1 consumed the lowest primary energy for embodied materials (0.39 x 10^4 MJ/m^2) but second highest materials replacement energy (0.29 x 10^4 MJ/m^2) when normalised to floor area. At the other end of the scale Building no. 6 has the highest embodied and materials replacement energy consumption among all the buildings, 0.55 x 10^4 MJ/m^2 of embodied energy and 0.4 x 10^4 MJ/m^2 replacement materials energy. The area normalised (per square metre) embodied energy is driven by both the energy intensity of the material utilised and the design structure of the building. Building no. 6 has a tiled roof, and significant quantities of steel, aluminium and insulation were used in construction. The primary energy for replacement of materials is influenced by the type and energy intensity of the materials used in the building. The lowest primary energy investment for materials replacement was 0.08 x 10^4 MJ/m^2 (Building no. 3).

The total life cycle primary heating for Building no. 1 (the reference building) was 1.33 x 10^4 MJ/m^2, the lowest primary energy consumption for heating load amongst all cases. Building no. 4 had the highest heating load, consuming over five times the primary energy for heating for a lifetime of 100 years when compared to the reference building. A combination of both heating and cooling loads contributes to the significant life cycle primary energy consumption of Building no. 4. Energy supply for heating in Australia is more efficient than energy systems supplying cooling loads. However, it is the magnitude of heating required and not the inefficiency of the supply system that drives the lifetime primary energy consumption of the cases discussed. Building no. 5 consumed the highest cooling loads with 1.82 x 10^4 MJ/m^2 closely followed by Building no. 4 with 1.51 x 10^4 MJ/m^2 and Building no. 1 (the reference building) with 1.48 x 10^4 MJ/m^2. Building nos. 8 and 3 consumed the lowest cooling loads among all the buildings. The lifetime primary energy for supplying cooling load was 0.19 x 10^4 MJ/m^2 for Building no. 8 and 0.59 x 10^4 MJ/m^2 for Building no. 3. Building no. 1 consumed over seven times and Building no. 5 nine times the lifetime primary energy to supply cooling loads over the 100 years than Building No. 8.

Buildings 3, 4, and 5 (timber construction) demonstrate the highest operational energy consumption of all the case studies, due to high heating loads. However, Building nos. 3, 4 and 5 have lower lifetime primary energy for materials replacement. Building Nos. 8 and 2 (mass construction) have significantly lower cooling loads but higher heating loads than Building no. 1. Building nos. 6 (brick veneer) is the most energy intensive in terms of embodied energy and replacement materials energy. Apart from Building no. 6, all the other buildings have a lower lifetime primary energy materials replacement compared to the reference building, Building no. 1.

6 DISCUSSION

Operational energy usage varies depending on the efficiency of the building and its systems, the way in which a building is used, and the prevailing climate. Management i.e. routine repair and maintenance will also affect energy use. Varying climate conditions will lead to considerable differences in heating and cooling between buildings.

The energy embodied in different buildings varies depending on the materials and construction. This study of single family dwellings in Victoria has found that a significant proportion of the total energy consumption of these representative buildings is embodied in the materials, replacement and construction. Therefore, increasing operational energy efficiency alone may not result in minimum energy consumption over the whole building life cycle.

As discussed in section 2 above, as the operational energy is reduced, the embodied energy component is likely to become more significant in the life cycle energy analysis of buildings (Boardman, 2007; Itard, 2009). The relative values of the embodied and operational energies are an important factor in choosing design strategies. An increase in the embodied energy – if optimized to reduce operating energy – may be justified if it can result in a substantial decrease in life cycle energy use.

It is a commonly held view that embodied energy lost through building demolition and reconstruction is quickly recovered in building operations, and that the environmental benefits of redevelopment are greater than extending the life of an existing building through refurbishment. However, previous studies have found that taking into account the embodied energy in an existing building, it can take around 24 years before energy savings are realised by building new rather than renovating an existing building (Killip, 2006 cited in Boardman, 2007). Based on the findings of this study, if Building no. 3 (Figure 2) was demolished and replaced by Building no. 1 (Figure 1), the 5 Star rated building, then it would take an estimated 47 years to recover the embodied energy in operational savings. To achieve sustainable construction, energy efficiency should be considered in a life cycle analysis where embodied energy is included.

It is to be expected that the energy efficiency of new construction would be superior to older buildings – due to improved insulation and potentially with more energy efficient or renewable energy installations such as green energy, use of photo voltaics, more efficient heating and hot water systems, etc., resulting in better environmental ratings. Many studies have shown that operational energy exceeds embodied energy in the total energy of a building over its life span. However, this is not justification for wholesale replacement of the existing building stock that does not meet current standards. Retaining and upgrading existing buildings is more efficient; not only can operational performance be improved at less cost than demolition and new construction, existing infrastructure can be utilised, and significant 'hidden' embodied emissions from construction, materials replacement, and waste can be avoided. Therefore, retaining and adapting existing buildings can contribute to sustainable development.

This study does not include analysis of use or occupant behaviour – which is known to have an influence on operational energy efficiency (see Fay et al, 2000; Bell and Lowe, 2000; Meijer et al, 2009).

Whilst the technical performance of existing buildings can undoubtedly be improved, there is some concern that increasingly stringent requirements for energy efficiency and focus on ratings founded on operational energy performance could lead to conflict with cultural heritage significance and values associated with heritage buildings, for example, the replacement of important architectural features such as windows, or damage to historic fabric during upgrading work. This is an area of research that is largely unexplored.

7 CONCLUSION

Older buildings are often perceived as being in poor condition and operating very inefficiently– with high energy consumption. This research has shown that that using current simulation tools whilst many older buildings do not achieve the rating of new buildings, they do achieve somewhat higher than the estimated average rating of 2 Stars or less for dwellings built before 2004. This research indicates that in some aspects (e.g. cooling loads) the performance of some older buildings is comparable or better than a new building. When embodied energy and energy consumed in materials replacement is considered as part of the building life cycle, existing buildings offer advantages over new buildings in terms of environmental performance. Further research is needed on the impact of the life span of buildings on environmental performance, in particular, the effect of durability and extending the life of existing buildings in terms of resource use and LCA performance in comparison with new building.

This paper has presented the findings of an on-going Australian study to determine the life cycle energy for a range of existing buildings of varying construction dating from c.1880s to 2000 using Life Cycle Assessment (LCA). The next step is to assess the impact of various interventions on energy usage, including alterations to elements of the building envelope, installation of low-energy light fittings and appliances including heating, cooling and hot water systems. This will be followed by appraisal of a range of suitable design interventions that can be used to achieve acceptable levels of sustainability in heritage buildings that satisfies current building legislation requirements.

The information obtained from the study will provide an evidence base for informing policy, and be useful as a basis to achieve improvements in environmental performance of the older building stock. It is intended that the information obtained from this study will be used in informing both building surveyors and design practitioners, and the wider community regarding:

–the relative performance characteristics of heritage building archetypes and the environmental performance benefits that may be obtained from retrofits;

–the need to improve life cycle environmental performance of existing housing.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the project partners who provided funding for this research: the Heritage Council of Victoria, the Building Commission of Victoria, the Department of Planning and Community Development, the Office of the Victorian Government Architect (Department of Premier and Cabinet), and the Department of Sustainability and Environment, State Government of Victoria. The assistance of Dr David Rowe and Vicki Johnson is also gratefully acknowledged for providing information on several of the building case studies.

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BIOGRAPHICAL NOTES

A member of the Royal Institution of Chartered Surveyors, Paula Judson has 20 years experience in practice in the UK and Australia, including planning and development, conservation and adaptive re-use of heritage buildings, and project management. Paula currently works as a project manager for Heritage Victoria and is in the second year of a PhD at RMIT University in Melbourne where she is undertaking research on heritage buildings and sustainable development.

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[i] Energy generation in Victoria is heavily reliant on brown coal at base loads, and lower quantities of gas and hydropower are used at the margin. In the baseline scenario, electricity and gas supplied cooling and heating loads respectively.

[ii] The National Association of Home Builders (NAHB) in partnership with Bank of America conducted a comprehensive study regarding the life expectancy of home components. The study reports lifetimes of different home components based on telephone surveys with manufacturers, trade associations and research practitioners. Lifetime of home components is heavily influenced by the quality of maintenance provided by the home owner. The buildings were analysed based on a 100 year lifetime.

In this study a service life of 9 years is assumed for carpet, 10 years for glazing, 15 years for aluminium windows, 40 years for joinery, 50 years for wooden and vinyl floors, 100 years for masonry and insulation. For the structural elements (floors, framing and structural systems, roof and roof trusses, ceilings and walls) the lifetime of the component is equal to that of building