ENERGY AND GREENHOUSE GAS EMISSIONS IMPLICATIONS OF ALTERNATIVE HOUSING TYPES FOR AUSTRALIA

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ABSTRACT

Many cities around the world are looking for ways to reduce their per capita greenhouse gas emissions. The outward growth of cities from a central business district, typical of many cities around the world, is often seen as working against this goal and as unsustainable. This is especially the case in circumstances where this growth is not supported by the necessary infrastructure, often resulting in an increase in the use of private transport. However, alternative scenarios to contain the outward growth are being proposed. This paper provides a comparison of the energy demand and greenhouse gas emissions between typical detached outer-suburban housing currently being built in Australia's major cities and inner-city and -suburban apartments, which are increasingly seen as a legitimate alternative to the housing that is currently being built on our outer city fringes. By analysing the energy demand associated with the construction and operation of each housing type and for occupant travel it was found that the location of the housing and its size are the dominant factors determining energy use and greenhouse gas emissions. The findings from this analysis provide useful information for policy-makers in planning the development of our cities into the future, when faced with a growing population and an increasing need to minimise greenhouse gas emissions.

Keywords: greenhouse gas emissions; house size, style and location; urban growth

INTRODUCTION

The reduction of greenhouse gas emissions is arguably the most important environmental issue facing the global community in the 21st Century. Australia is one of the highest emitters of greenhouse gases in the world on a per capita basis (Turton 2004). Australia's Chief Advisor on climate change has warned that by 2050 Australia needs to reduce its emissions by approximately sixty percent (Garnaut 2008). A significant contributor to greenhouse emissions is suburban residential development (AGO 1999). One of the most noticeable changes in our urban landscape over the last 50 years has been the growth of our major cities outward from their original geographic centres. Population increase and Australians' desire to continue to enjoy low-density housing have driven this type of expansion. A familiar sight in most of our major cities, are new estates located far out from the urban centres. A dominant characteristic of the new houses is their size. The average house size has risen dramatically over the last 50 years and now new residences are well over 200 m^2, more than double the average in the 1950s.

Federal and State Governments in Australia have initiated various programs and legislation to both encourage and mandate reductions in greenhouse gas emissions. Efforts to limit greenhouse emissions in the southern state of Victoria are particularly critical due to its reliance on electricity produced from wet brown coal which has a high emission coefficient. The Victorian Government recently developed a blueprint, known as *Melbourne @ 5 Million,* for the growth of Melbourne over the next two decades (DPCD 2008). By 2036 it is predicted that an additional 1.8 million people will live in metropolitan Melbourne and will have created an additional 600,000 new households. *Melbourne @ 5 Million* acknowledged that the location of these households, the type of housing built and the travel choices of the occupants will be critical to the future sustainability of Melbourne and this is just as true for other Australian cities. Strategies to meet the needs of Melbourne's future residents, while restricting greenhouse gas emissions, have been proposed. These include increasing public transport patronage to 20% and mandating the energy efficiency of new housing stock in designated growth areas. While some research has investigated the impact of these and similar measures individually (AGO 1999; Treloar *et al.* 2000), their combined effect has not been evaluated. This paper describes research undertaken to assess the combined impact on energy demand and greenhouse gas emissions of current and future residential development in the light of the housing and transport strategies proposed in *Melbourne @ 5 Million*. A previous study by the authors (Fuller and Crawford 2011) considered the implications of different housing types in Melbourne. This paper builds upon this study by providing a comparison of the energy demand and emissions of these different housing types located in both Melbourne and Brisbane, representing distinctively different climatic regions of Australia.

1. BACKGROUND

Australian cities have grown significantly since the end of the Second World War. Initially in the post-war housing boom, any vacant land in the older suburbs was used for new housing. As older suburbs 'filled up', new suburbs were developed and populated. Dingle (1995) describes this process - "At any time the outer ring of suburbs - the suburban frontier - is the city's main breeding zone and the main residential building site". Mees (2000) discusses the growth of Melbourne's suburbs in relation to its public transport network and the difficulties experienced by its population to use this system effectively. These difficulties, both real and perceived, have led to a continued decline in public transport use and increasing dependence on the private motor car, evidenced in all of our major cities. The extent to which the motor car has shaped the development of our cities and its housing since 1950 is documented extensively by Davison and Yelland (2004). However, none of the above authors have discussed this suburban growth in environmental terms, particularly greenhouse gas emissions.

The outward growth of our cities has had a significant environmental impact because most householders are now forced to travel significant distances to their workplace. Greenhouse gas emissions from transport in Australia represent 15.3% of the country's total, but emissions from cars represent 50% of the transport emissions (Department of Climate Change and Energy Efficiency 2011). Despite some recent increases in public transport patronage, most work-related travel is still by car. Previous research has determined the average energy and greenhouse gas intensities for various modes of transport in Australia (Lenzen 1999), showing that per passenger-kilometre, car travel produces twice the greenhouse gas emissions of train travel. This data includes both the direct and indirect energy requirements associated with travel. The indirect energy requirements include the energy used to provide the entire infrastructure required for both passenger car and train travel. The increasing size of Australian houses has also had a significant effect on national energy demand and greenhouse gas emissions. Larger houses have meant more energy is required to manufacture the greater quantity of materials needed in their construction (known as their embodied energy) and to run the heating and cooling systems, and appliances within them (their operational energy).

1.1. Current housing in Australia

The most common type of housing in Australia is detached (Kelly *et al.* 2011), making up 70% of new housing built in 2010 (ABS 2010b). The average floor area of this type of housing is now 243 m^2 (Johanson 2011), up 7% in the past 10 years alone and over 162% since 1950 (ABS 2010c). These houses are increasingly located away from existing public transport networks, increasing the reliance of householders on private car transport. Another characteristic of housing in Australia is the declining household size, which has declined 30% over the past 60 years to an average of 2.5 people per household (ABS 2010d).

1.2. Alternative housing types

In recent years, various alternatives to traditional detached housing have begun to emerge in many Australian cities. For example, there has been a growth in the preference for inner-city living and new high-rise residential housing has been built on previous commercial sites like the former Docklands in Melbourne. While the construction of new houses on outlying greenfield sites still continues, some of this (in Australian terms anyway) demonstrates high levels of thermal efficiency and has reasonable access to public transport. Finally, some medium-density housing is being built within the existing suburbs, which is responding to the desire (and need) for more sustainable housing and a changing demographic. These three alternative housing types are described below.

1.2.1 Energy-efficient greenfield outer-suburban detached housing

One scenario proposed for future development is a continuation of the current low-density housing trend, moving even further away from the CBD than the existing outer suburbs. It is suggested, however, that the additional energy use and greenhouse impacts associated with this form of development, in particular due to additional travel distances, can be offset by improvements to the thermal performance of the house as well as locating these houses close to public transport. Such houses are now being constructed on the outer fringes of our major cities.

In May this year the requirement for new houses to meet a minimum 5-star standard for heating and cooling energy demand rose to 6 stars, lowering the maximum threshold for heating and cooling energy demand (ABCB 2010) – the higher the star rating the lower the amount of energy needed for heating and cooling. Government regulation will continue to require increasing energy efficiency in new houses and thus lowering of this threshold is likely to continue into the future forcing new home owners to further reduce the energy used for heating and cooling within their households. While the ultimate goal is to produce houses with zero emissions from operational energy requirements, this study assumes a goal of 8 stars is feasible within the short term. It is believed that by reducing heating and cooling energy demand to a level equivalent to 8 stars (25 and 54 MJ per m^2 for Brisbane and Melbourne respectively) (Sustainability Victoria 2008), any additional demand for energy can be met by renewable energy.

1.2.2 Inner-suburban medium-density apartments

In an attempt to create more affordable housing, medium-density apartments are emerging within the inner suburbs of our major cities, typically between three and five storeys high. An example of this type of housing is the 96 public housing apartments, known as the K2 Apartments, located in an inner Melbourne suburb. Described as an ecologically sustainable medium-density housing development, the apartments cover a 4,800 m^2 site for approximately 150 tenants and were completed in early 2007. Energy conservation and renewable energy technologies have been used to substantially reduce greenhouse gas emissions. The design also uses both recycled materials and materials with recycled content. For example, the concrete used includes fly-ash, a by-product of the coal combustion process, used to replace the highly energy-intensive cement used in traditional concrete.

While the inclusion of these various technologies may help to reduce operational energy and water consumption within the building, an increase in embodied energy results from the increase in the use of materials required for these systems. In particular, significant increases are likely due to the energy-intensive manufacturing practices for photovoltaic cells (Crawford *et al.* 2006). It is assumed in this case, however, that the additional embodied energy resulting from the inclusion of these systems is offset by the embodied energy savings from utilising recycled materials and materials with recycled content.

1.2.3 High-rise inner-city apartments

Increasingly common in the inner-city areas of our major cities are high-rise apartment buildings such as those built within the Docklands area, two kilometres west of the Melbourne CBD. These apartment buildings are typically around 20 storeys in height and are a reinforced concrete structure with a high proportion of glazed external walls. The apartments vary in size, depending on the number of bedrooms, but the majority have two bedrooms and are approximately 100 m^2 in area. In line with the Building Code of Australia (ABCB 2010) an average of a 6-star energy rating must be achieved across all apartments with a minimum 5-star rating for each individual apartment.

Table 1 provides a summary of key data (dwelling size, distance from the CBD, number of occupants) used together with operational and embodied energy and travel data to calculate the energy use and associated emissions for each housing type.

Table 1: Size, distance from CBD and occupancy level, by housing type

Housing type	Dwelling area (m^2)	Distance from CBD (km)	Number of occupants
Outer-suburban detached housing (6-star)	248	37	2.5*
Outer-suburban detached housing (8-star)	248	37	2.5*
Inner-suburban medium-density apartment	64	4	1.6
High-rise inner-city apartment	100	2	1.9^

Source: *(ABS 2010d), ^(ID 2011)

One of the most significant issues with previous research is the focus on operational energy demand of housing. Previous studies have shown that the embodied energy and travel energy demand can be of even greater significance over the life of a building (Newman 2006; Fuller and Crawford 2011). The use of a more comprehensive approach, as used in this study, can provide a more realistic assessment of the energy demand and emissions associated with different types of housing.

1.3. Embodied energy

Embodied energy (EE) is the energy associated with the manufacture of products and materials, including the energy used in the manufacture of goods and services used during this process. The recurrent embodied energy (REE) of buildings accounts for the additional requirements for building products used in maintenance and repairs over the life of the building.

A process analysis is the approach typically used to quantify the embodied energy figures in most, if not all, existing tools and previous studies. This type of analysis relies on process data, collected from individual material manufacturers, which is known to result in an incomplete coverage of the total energy associated with any product or process. This can lead to embodied energy values that are up to 87% incomplete due to the representation of the product system by a finite boundary and the omission of contributions outside this boundary (Crawford 2008). This leads to various forms of truncation of the system boundary where inputs upstream, sideways and downstream of the main material inputs can be excluded (and thus the energy associated with these processes).

Hybrid analysis methods have been developed in an attempt to minimise the limitations and errors of traditional embodied energy assessment methods (Crawford *et al.* 2010). The input-output-based hybrid analysis approach developed by Treloar (1997) addresses many of these problems by starting with a disaggregated input-output model to which available process data is integrated. The input-output model is based on national average input-output data that models the financial flows between sectors of the economy to represent the flow of goods and services between them (Treloar *et al.* 2001). These financial flows can be converted to energy terms with the use of energy tariffs for embodied energy analysis. Using this data it is then possible to quantify the energy embodied in any product or service produced within the economy. The advantage of an input-output model is that it enables a systemically complete analysis of the energy requirements associated with any product system. However, as it is based on national average data, its use does limit the applicability and reliability of results for any specific product. A more in-depth analysis of the implications of using a process analysis versus a hybrid analysis approach for embodied energy assessment is provided by Suh *et al*. (2004).

2. METHOD

This section describes the approach used to determine the energy and greenhouse gas emissions of current detached housing common in Australian cities as well as the selected alternative housing types. The analysis includes the energy and emissions embodied in the initial construction and ongoing maintenance and repair of each type of housing, the operational energy requirements and emissions (for heating, cooling, appliances, cooking, lighting and hot water) and energy and emissions associated with work-related travel.

A built example of a typical new detached outer-suburban house was used to analyse the energy and emissions implications of the most common type of housing being built in Australian cities. This house is single-storey and constructed of brick veneer, concrete slab floor and concrete tiled roof (Fig. 1). The floor area of the house is 247.6 m^2, corresponding with the average size of new detached housing in Australia.

Source: Plan based on Metricon (2010)

Figure 1: South elevation and floor plan of 6-star detached house

The characteristics of the three alternative housing types were determined (floor area, construction type and materials, household size, distance from CBD) based on the existing examples of these types of housing as discussed above in Section 1.2. For example, the 8-star house was identical to the 6-star house described above but rammed earth walls replaced the external brick veneer walls, all windows were double-glazed and ceiling insulation levels were increased in thickness by 20 mm.

The analysis of the high-rise apartment building and medium-density apartment building has been based on a typical apartment building based in the Melbourne Docklands and inner suburbs of Melbourne, respectively. For the inner-city apartment, an average total floor area of 100 m^2 was used. The main construction type was insulated concrete precast panels with floor-to-ceiling glazed windows. For the inner-suburban apartment the average apartment size used was 64 m^2.

The energy and greenhouse gas emissions analysis was performed for each of the housing types for both Melbourne and Brisbane, representing distinctly different climates, as geographic location can often have a significant effect on the operational energy and emissions of housing.

2.1. Embodied energy

The input-output-based hybrid approach, integrating available process data with national average input-output data, was used to calculate the EE of the three housing types. The embodied energy associated with the initial construction (initial embodied energy) and the additional requirements for building materials used in maintenance and repairs (recurrent embodied energy) over an estimated period of 50 years, was calculated.

The base input-output data was taken from the Australian National Accounts (ABS 2001) and combined with energy intensity factors by fuel type. The combination of these two sources comprises the input-output model. The model includes the value of capital purchased in previous-years, and capital imported from other countries, amortised over the capital items life, as described by Lenzen and Treloar (2004). Capital refers to the equipment and machinery used to make products. The input-output model was used as the basis for the embodied energy analysis of the housing types. The best available process energy data was incorporated for specific material manufacturers as per the input-output-based hybrid approach (Treloar 2007) to form hybrid material energy coefficients for a range of common building materials. Process data was obtained from the latest available SimaPro Australian database (Life Cycle Strategies 2011). The use of input-output data here resolves any upstream truncation errors for these materials. The quantities of the materials used in each of the housing types were multiplied by their respective energy coefficients and the sum of these results gave the total process-based hybrid embodied energy for each housing type. These values were then substituted within the overall input-output model to complete the system boundary, removing any instances of sideways or downstream truncation. To do this the total energy requirement value of the input-output pathways for which physical quantity data was obtained, was deducted from the total energy requirement of the ‘residential construction’ sector to give the ‘remainder’. The remainder corrects for sideways and downstream truncation errors.

Recurrent embodied energy was calculated by assigning replacement rates to materials used in the initial construction of each housing type. Little data currently exists for the anticipated life of building materials in Australia. Maintenance and replacement periods for materials were estimated with consideration of the likely exposure to deteriorating effects for each material. The estimated useful life or replacement period for the materials used in the houses can be found in Crawford *et al.* (2010). It is acknowledged that the embodied energy values associated with the replacement of materials over the life of the building will change over time due to factors such as changes in manufacturing procedures. However, for the purpose of this study it was assumed that the REE figures would remain constant.

The life cycle embodied energy of each housing type was calculated using Equation 1.

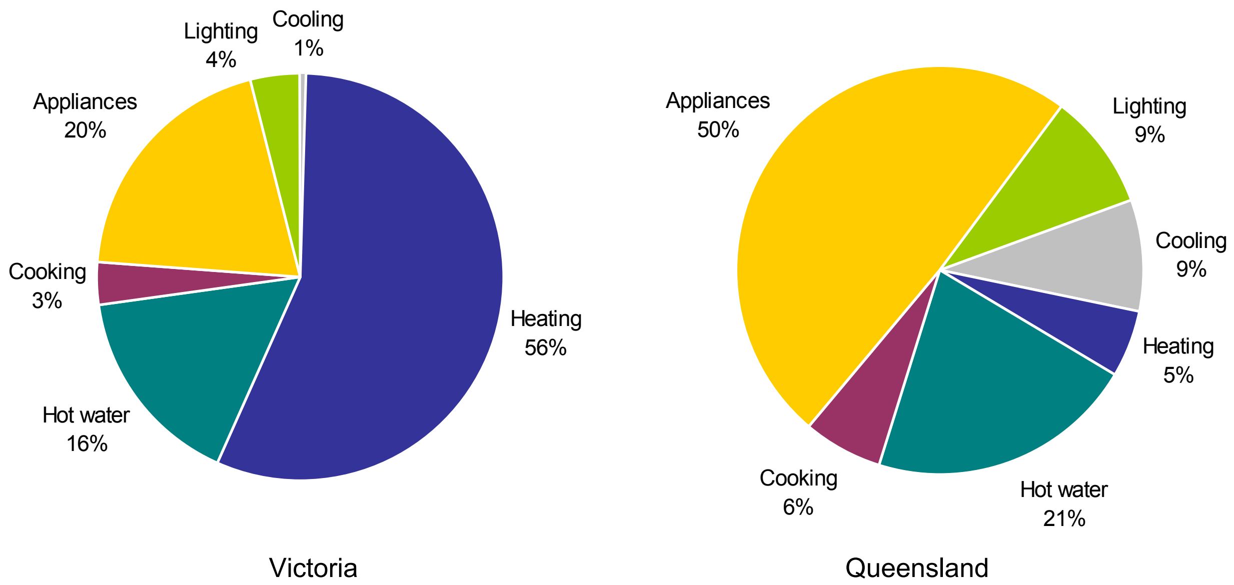
$$LCEE_h = \sum_{m=1}^{M}\left(\frac{UL_h}{UL_m}\times EE_m\right)+\left(TER_{rc}-\sum_{m=1}^{M}(TER_m)\right)\times\frac{\$_h}{1{,}000} \qquad (1)$$

Where $LCEE_h$ is the life cycle embodied energy of the housing type; UL_h is the useful life of the housing; EE_m is the embodied energy of material, m; UL_m is the useful life or replacement period of material, m; TER_{rc} is the total energy requirement of the residential construction sector, in GJ per \$1,000; TER_m is the total energy requirement of the input-output pathways for which process data was obtained, in GJ per\$1,000; and $\$_h$ is the total cost of the housing type.

For the medium-density and high-rise apartments, LCEE was calculated for the entire building (in GJ/m^2). These figures were then multiplied by the average individual dwelling area (Table 1) to determine the total LCEE of each housing type. Over a building life of 50 years each occupant would theoretically be annually ‘responsible’ for their share of 2% of the total LCEE of each individual house or apartment. The annual EE of each housing type was divided by the number of occupants (Table 1) to determine the energy for which each occupant is responsible, which was then summed with annual operational and travel energy demand.

2.2. Operational energy

Operational energy and emissions were determined for each housing type for both Melbourne and Brisbane. Householders use energy to meet a variety of needs. These include heating, cooling, heating water, cooking, lighting, general power, refrigeration, clothes drying and entertainment. The breakdown of predicted energy use for major end uses in an average Victorian and Queensland home in 2011 is shown in Figure 2.



Source: based on DEWHA (2008)

Figure 2: Household energy use by end use in Victoria and Queensland in 2011

2.2.1. Heating and cooling

Annual energy use for heating and cooling was based on the maximum allowable energy consumption for heating and cooling defined by the mandatory energy rating scheme (ABCB 2010) and energy use predictions from Sustainability Victoria (2008) which provides heating and cooling energy use predictions per unit area in 69 climatic regions, by star rating. The energy use predictions used in this study are shown in Table 2. The ratio of heating and cooling energy components was assumed based on energy consumption data from DEWHA (2008: Table 8 and 9).

Table 2: Heating and cooling energy use predictions, by housing type

House Type	Combined heating and cooling energy use (MJ m^{-2})	
	Melbourne	Brisbane
Outer-suburban detached housing (6-star)	114	43
Outer-suburban detached housing (8-star)	54	25
Inner-suburban medium-density apartment	114	43
High-rise inner-city apartment	114	43

The estimates of heating and cooling energy presented above are for 'demand' or delivered energy, i.e. the energy required to heat or cool a particular space. In order to determine the 'bought' or consumed energy, the appliance efficiency must be included to determine the amount of energy used or 'bought' by the householder. The AGO recommends that gas space heating and cooling appliance efficiencies of 70% and 250% be used respectively (AGO 1999: Table 77). When comparing predictions with actual usage, the AGO study found that the predictions of 'bought' energy needed to be modified by a 'constraint' factor to more accurately match actual usage. The constraint factor reflects a combination of occupancy level and zoning. Constraint factors of 0.45 and 0.4 for the heating and cooling energy were recommended for Victorian households and 0.25 and 0.4 for the heating and cooling energy for Queensland households (AGO 1999: Figure 1) and these values have been used.

Factors of 1.3 and 3.4 for Victoria and 1.3 and 3.1 for Queensland were used to convert delivered energy to primary energy for gas and electricity respectively. Accordingly, heating and cooling energy consumption figures for each year were determined by using the general relationship shown below (Equation 2).

$$OE = UE \times CF \times A \div \eta \times PE \tag{2}$$

Where UE is the unconstrained energy use prediction (MJ m^{-2}); CF is the constraint factor (dimensionless); A is the house area (m^2); η is the appliance efficiency (decimal); and PE is the primary energy factor (dimensionless).

2.2.2. Appliance use, water heating, lighting and cooking

Per capita energy use for water heating has been calculated using the data from DEWHA (2008: Table 6) and population data (ABS 2010a). The DEWHA data is based on bottom-up end use modelling, which has been verified where possible by the report's authors against a variety of other sources (p.6). The simulated data covers the period between 1990 and 2020. A similar technique was used with similar levels of correlation to calculate per capita use of energy for cooking, lighting and the operation of appliances. The annual energy use figures for both Victoria and Queensland are shown in Table 3. The significance of appliance energy usage reflects the increasing number of appliances in homes.

Table 3: Estimates of annual per capita energy use for water heating, cooking, appliance use and lighting in Victoria and Queensland

Location	Water Heating (MJ)	Cooking (MJ)	Appliances (MJ)	Lighting (MJ)
Victoria	4,868	1,010	6,040	1,187
Queensland	2,769	820	6,447	1,187

2.3. Energy for work-related travel

There is a high rate of car ownership in Australia. In 2010, there were 12.2 million registered passenger vehicles for a population of 22.3 million, i.e. 1.4 vehicles per household (ABS 2010e). In this study, however, the energy contribution of only one car has been considered, assuming that it has been used for daily travel to and from work in the Central Business District (CBD) of either Melbourne or Brisbane. Distances from the housing type to the CBD have been assumed and are shown in Table 1. It has been assumed that the average employed person works for 48 weeks of the year and travels to and from work on five days per week. The mode of travel to work is either by train or by car. A significant increase in car travel over the past 60 years has mirrored the decline in the use of public transport reported by Mees (2000), although over recent years, patronage of Australia's public transport systems has increased due primarily to rising oil prices. The percentage of trips made by train and car is given in Table 4 for each housing type. Travel distances for each housing type have been assumed to be the same for both Melbourne and Brisbane, although this is unlikely to be the case for cities with varying populations or population densities.

Table 4: Percentage of trips to and from work made by train and car, by housing type

Housing type	Percentage of Trips by Train (%)	Percentage of Trips by Car (%)
Outer-suburban detached housing (6-star)	9	91
Outer-suburban detached housing (8-star)	30	70
Inner-suburban medium-density apartment	50	50
High-rise inner-city apartment	75	25

To calculate the energy used for the work trips each year, average energy intensity figures in Australia for the two modes of transport used have been assumed (Lenzen 1999). This data includes both the direct and indirect energy requirements associated with the travel. The indirect energy requirements include the energy used to provide the infrastructure required for both passenger car and train travel. The total energy requirements for local train and urban car travel used in this paper are 2.8 and 7.0 MJ per passenger-km respectively (Lenzen 1999: Table 2).

To calculate the annual travel energy (*TE*), Equation 3 was used.

$$TE = ADT \times ((TP \times EI_t) + (CP \times EI_c)) \qquad (3)$$

Where *ADT* is the annual work distance travelled (passenger-km); *TP* is the percentage of train travel; EI_t is the energy intensity of train travel (GJ/passenger-km); *CP* is the percentage of car travel; and EI_c is the energy intensity of car travel (GJ/passenger-km).

2.4. Greenhouse gas emissions

The greenhouse gas emissions associated with the embodied energy in the materials used in the housing types have been calculated using a constant figure of 70 kg/GJ (AGO, 1999; Table 77, p.103). The greenhouse gas emissions for heating, cooling, water heating, lighting and appliance use have been calculated using the emissions coefficients of 0.382 (Victoria) and 0.283 (Queensland) kg per MJ for electricity and 0.0553 (Victoria) and 0.0599 (Queensland) kg per MJ for gas (Department of Climate Change and Energy Efficiency 2010). These figures include the emissions associated with the primary energy used in the production of 'bought' energy. Therefore, the operational energy figures were reduced by dividing by the primary energy factors, prior to calculating the greenhouse emissions, to avoid their double counting. To calculate the greenhouse gas emissions associated with work-related travel, direct conversion from kilometres to kilograms has been made using emission coefficients of 0.27 and 0.55 kg per passenger-km for train and car travel respectively (Lenzen, 1999).

3. RESULTS AND DISCUSSION

This section presents the results of the energy and emissions analysis of the four housing types, including their initial and recurrent embodied energy, operational energy requirements and energy associated with work-related travel, as well as the emissions associated with each of these items.

3.1. Embodied energy

Initial and recurrent embodied energy were combined for each housing type and divided by the household size (Table 1) to determine the quantity of embodied energy that each household occupant was annually responsible for over 50 years (Table 5).

Table 5: Life cycle embodied energy per capita, by housing type

Housing type	Initial embodied energy (GJ)	Recurrent embodied energy (GJ)	Life cycle embodied energy (GJ)	Annualised embodied energy (GJ)
Outer-suburban detached housing (6-star)	3,994	1,780	5,774	46.2
Outer-suburban detached housing (8-star)	3,737	1,521	5,258	42.1
Inner-suburban medium-density apartment	1,394	418	1,812	22.6
High-rise inner-city apartment	2,333	700	3,033	31.9

3.2. Operational energy

Table 6 shows the data used to calculate the operational energy for the four housing types described above. Heating and cooling energy requirements are based on the combined maximum annual energy use per unit area required under the performance rating system (Sustainability Victoria 2008; ABCB 2010). The ratio of heating and cooling energy components has been assumed based on energy consumption data from DEWHA (2008: Table 8 and 9).

Table 6: Figures used to determine annual operational energy requirements, by housing type

Housing Type	Heating Energy (MJ m^{-2})	Cooling Energy (MJ m^{-2})	Water Heating (MJ p^{-1})	Cooking (MJ p^{-1})	Appliances (MJ p^{-1})	Lighting (MJ p^{-1})
Melbourne						
Outer-suburban detached housing (6-star)	112.92	1.08	4,868	1,010	6,040	1,187
Outer-suburban detached housing (8-star)	53.49	0.51	4,868	1,010	6,040	1,187
Inner-suburban medium-density apartment	112.92	1.08	4,138[a]	1,010	6,040	1,187
High-rise inner-city apartment	112.92	1.08	4,138[a]	1,010	6,040	1,187
Brisbane						
Outer-suburban detached housing (6-star)	16.38	26.62	2,769	820	6,447	1,187
Outer-suburban detached housing (8-star)	9.52	15.48	2,769	820	6,447	1,187
Inner-suburban medium-density apartment	16.38	26.62	2,354[a]	820	6,447	1,187
High-rise inner-city apartment	16.38	26.62	2,354[a]	820	6,447	1,187

[a] It has been assumed that a centralised hot water system is 15% more efficient than the average individual system.

3.3. Energy for work-related travel

It has been assumed that the proportion of work-related travel made by train for the three alternative housing types is significantly greater than for current detached housing (Table 4). For example, for the outer-suburban 8-star housing type, it was assumed that the proportion of travel by public transport would be 30% due to the proposed proximity of this type of housing to public transport, compared to existing relatively poor access to public transport in the existing outer-suburban areas. Table 7 shows the annual energy required for work-related household travel for each housing type.

Table 7: Annual household work-related travel energy, by housing type

Housing type	Private travel energy (GJ)	Public travel energy (GJ)	Total travel energy (GJ)
Outer-suburban detached housing (6-star)	113.1	4.5	117.6
Outer-suburban detached housing (8-star)	87.0	14.9	101.9
Inner-suburban medium-density apartment	6.7	2.7	9.4
High-rise inner-city apartment	1.7	2.0	3.7

3.4. Energy implications of alternative housing types

Figure 3 compares the various per capita energy consumption levels for the four housing types considered. All three alternatives use less energy than the current 6-star detached housing for both Melbourne and Brisbane. Total energy use per capita in the 8-star house is, however, only 11-13% less than in the 6-star house, whereas the apartments result in a reduction in energy use of 56-62%. There is a minor reduction in operational energy consumption for the housing in Brisbane resulting from a reduced demand for energy for heating and hot water due to higher ambient temperatures. However, embodied energy per capita significantly exceeds the operational energy for all housing types, although it is significantly lower for the apartments, indicating that an increasing focus from building designers on this component of total energy use is most critical. The most significant reductions are made in travel energy for the two apartments, where energy use falls by 96% and 88% for the high-rise inner-city and the suburban apartments respectively, compared to the 6-star detached housing. Despite being located close to public transport and an increase in usage from 7% to 30%, travel energy per capita has fallen only 13% for the 8-star house due to its significant distance from the CBD.

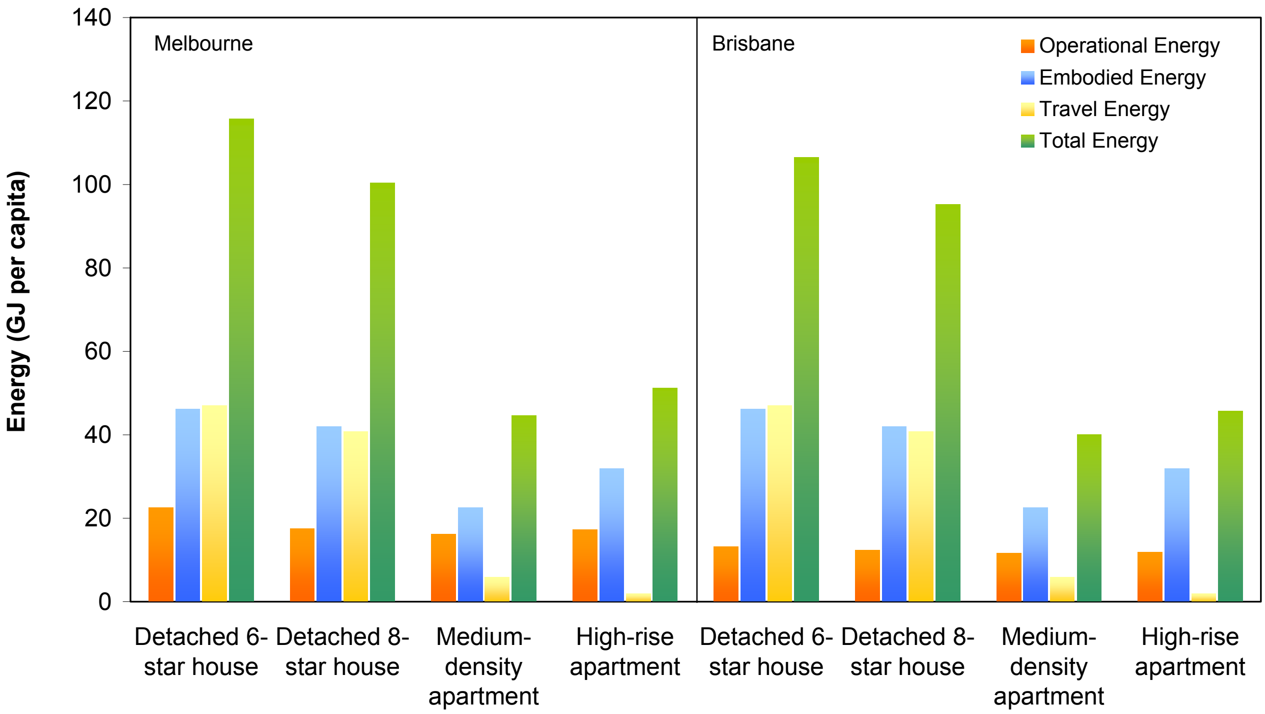


Figure 3: Annual per capita energy consumption for Melbourne and Brisbane, by housing type

3.5. Greenhouse gas emission implications of alternative housing types

Figure 4 shows the per capita greenhouse gas emissions (CO_2-e) of the four housing types, and in terms of total emissions, a similar pattern to per capita energy use can be observed. Emissions for all three alternative housing types fall with respect to the 6-star detached house. Compared to the 6-star house, reductions vary from 53% for the suburban apartment in Brisbane to only 8% for the 8-star house in Brisbane. Operational emissions are lower in Brisbane due to a lower energy demand for combined heating and cooling as well as the use of less emissions-intensive electricity. For the detached housing types, travel emissions dominate, contributing 35-39% of the total. The suburban apartments generally outperform all other options, except for the transport emissions of the high-rise apartments. Overall, the suburban apartments appear to result in the lowest greenhouse emissions due to the smaller apartment size reducing embodied emissions, despite slightly higher travel emissions.

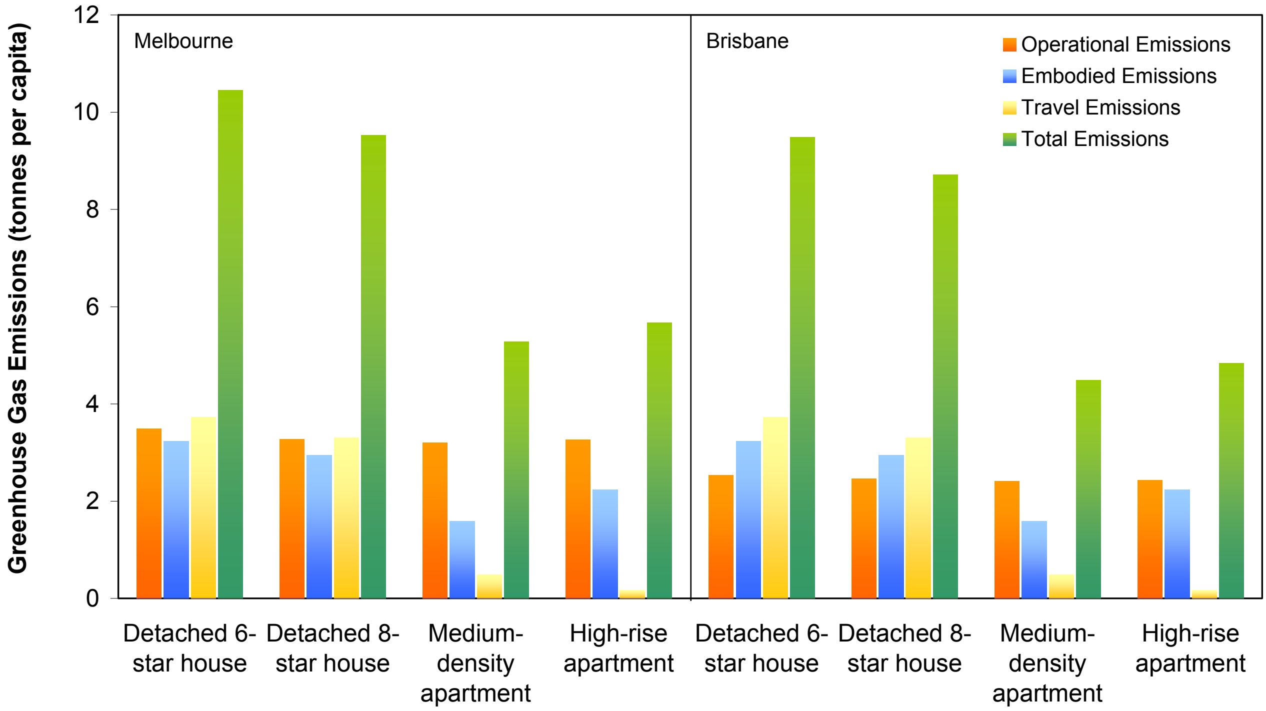


Figure 4: Annual per capita greenhouse gas emissions for the alternative housing scenarios

The authors acknowledge that this analysis is based on hypothetical scenarios of the housing and the associated choices by the occupants. However, this is not an unrealistic description of reality. House sizes and car use for work travel have both increased, family sizes have declined and people are living further and further out from the centre of our major cities. The census data confirm these trends. The hypothetical scenarios considered enables the relationship between the size and style of house and where it is located to be clearly identified.

It is also acknowledged that there are other factors that may mitigate the clear reductions in energy use and associated emissions from apartment living in the inner suburbs and city centre compared to building on its outer edges. These factors include: an increase in the heat island effect that may drive up cooling needs, more travel by inner-city residents for recreational activities and a general rise in inner-city pollution levels due to the increased population. However, including these effects is beyond the scope of this study and would require a whole-of-city analysis, rather than one that focuses on individual home owners, as is the case here.

CONCLUSION

This paper has assessed the combined effect on energy demand and greenhouse gas emissions of current and alternative housing types. Of the housing types analysed, it appears that the type of housing that has the greatest potential to reduce energy consumption and greenhouse emissions are the inner-suburban and inner-city apartment-type buildings. This study has shown that inner-suburban residents may be able to reduce their total annual energy consumption and emissions by 49-62% compared to the outer-suburban detached housing currently being built in many of our major cities.

While in reality, detached housing is going to continue to make up a significant proportion of our housing stock, this study indicates that a focus towards greater population densities, reduced reliance on private transport and smaller houses is likely to lead to the greatest reductions in household-related energy consumption and associated emissions. Although the scenarios investigated are necessarily idealised, they are indicative of current trends and possible future housing types. As such the scenarios provide useful insight into the relativity between operating, embodied and travel energies and emissions. Whilst this study focuses on the cities of Melbourne and Brisbane, it is possible to apply the methodology and findings to similar cities across the world in an attempt to identify opportunities for reducing energy demand and greenhouse gas emissions. Changes to the assumptions made in this study, including travel modes and distances, vehicle fuel efficiency, occupancy rates, household energy usage, construction materials and embodied energy intensities, will alter the findings to varying degrees.

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