

ENVIRONMENT DESIGN GUIDE

THE RELATIONSHIP BETWEEN HOUSING DENSITY AND BUILT-FORM ENERGY USE

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Abstract

Since the advent of the motor vehicle, Australian urban fabric has been characterised by low-density development. Increasingly the impact of this low-density urban sprawl on native vegetation, infrastructure, pollution and transport use has led to policies aimed at encouraging urban consolidation.

Consolidation of the urban fabric is seen as a means to reduce energy consumption and thus greenhouse gas emissions. However, the relationship between high-density housing and low energy use is not automatic. Although urban consolidation can lead to lower transport energy use, research shows that planners, designers and policy makers may not have sufficiently taken into account built-form energy use by different housing types.

This paper looks at the need for more research into this area, to better inform urban planning policies as well as the design of individual buildings.



Figure 1. High-density developments are not giving urban planners the smaller environmental footprint they'd hoped for. (Image: iStockphoto.com)

INTRODUCTION

Australian urban development in the 20th century was characterised by low-density development. More recently, recognition of the limits to low density urban sprawl has led to policies aimed at encouraging urban consolidation (UFP 2003).

Increasingly, Australian planning policies have sought to increase urban densities through consolidation. Urban consolidation increases dwelling densities within established areas above the existing density, and may occur through infill development or the redevelopment of existing buildings. Urban consolidation aims to make more efficient use of existing infrastructure and restrict the spread of urban development into surrounding rural areas (Infrastructure Australia 2010 and ACTPLA 2004). Higher density housing through urban consolidation has also been presented as a means to reduce energy consumption and greenhouse gas emissions (Sustainable Solutions 1998).

This paper concentrates on the relationship between housing density and built-form energy use; built-form energy use being that required to build and operate buildings as opposed to that required for travel by the residents.

The relationship between housing density and transport energy use is already well researched; with numerous studies establishing that transport energy use is lower on a per capita and per household basis in higher density areas (Tarlo 2002 and Newman & Kenworthy 1999). Studies have also identified that other features, combined with housing density, impact on transport energy use. These include employment density and activity intensity, local land use mix, spacing of employment centres and neighbourhood design and street layout (Gray, Gleeson and Burke 2008). However, there has been limited study of the relationship between housing densities and energy consumption at a dwelling or subdivision level.

Current Australian research on this topic is dominated by studies completed during the last decade. These studies have used a range of methodologies which include different comparison areas, sample sizes and variables, making them difficult to compare. Hence the results from these studies should be considered as indicative of general trends rather than as conclusive, and help state the case for further research. If this research clarifies the relationship between housing density and building energy use, it will inform planning and environmental policies, as well as the design of future dwellings.

POLICIES ENCOURAGING INCREASED DENSITY

In most major Australian cities, the norm for urban development policies is to encourage an increase in residential densities. This planning trend has emerged because of concern over the expanding footprint of cities, desire to protect surrounding undeveloped land, and planning theories such as that of the 'compact city'.



Figure 2. Townhouse
(Image: SGS Economics and Planning)

Compact city policy is based on the concept that increasing the population and density of inner suburbs will reduce fringe development and travel distances (Scheurer 2001). This is supported by studies that show the compact city, when compared to other city models, is best able to reduce CO₂ emissions and air pollution, by reducing vehicle kilometres travelled (Newton et al. 1998).

The trend towards compact cities and urban consolidation is reflected in current metropolitan planning policies for Adelaide, Canberra, Melbourne, Sydney, Perth and Brisbane. In Sydney, it is estimated that up to 70 per cent of future development will occur within the existing urban area through higher density developments. If development over the next 30 years continues as recommended by the Sydney Metropolitan Strategy, it is anticipated that by 2030 multi-unit housing will account for 45 per cent of Sydney's total housing stock, up from 33 per cent of the current proportion of attached dwellings (Randolph 2005). However it is expected that despite this, single detached dwellings will remain the dominant housing form in Australia (ABS 2004).

The push for higher densities has also been tied to shrinking household size, where the average household size has fallen from 3.6 persons per household in

1954, to 2.56 persons per household in 2007–08 (ABS 2009). Interestingly, as household sizes have decreased, new dwelling sizes have increased, with an increase of almost 38 per cent (from 149.7 m² to 205.7 m²) between 1984–85 and 2002–03 (ABS 2005). This trend towards increased floor area appears to conflict with metropolitan planning policies that advocate higher density housing, which would be expected to result in reduced dwelling sizes. The increase in housing floor area also has significant implications for the consumption of building materials, furniture and appliances, and as a result, is another source of increasing energy demand (Newton 2001).

Until recently, arguments for and against increasing housing density have focused on transport, air pollution and native habitat issues. Exceptions include the Victorian Government’s *Greenhouse Neighbourhood* and *Urban Villages* projects in the 1990s, which analysed the energy use of different models of suburban development at ‘greenfield’ sites on the fringe of metropolitan Melbourne (DPD 1993).

RESIDENTIAL ENERGY USE AND CO₂ EMISSIONS

Household consumption is responsible for around 56 per cent of Australia’s total energy related emissions. This proportion is high due to a household’s sphere of influence extending beyond the residential sector (Bunker and Holloway 2002). Private consumption behaviour contributes to Australia’s high per capita emission of greenhouse gases through an increased reliance on private motor vehicles, increasing house sizes, and higher expectations of comfort, particularly regarding the heating and cooling of buildings and vehicles (RMIT 2003). Changing expectations and increased levels of personal wealth have also contributed to increased energy use per capita (Newton 2006).

Increasing recognition in Australia of the potential impacts of climate change has resulted in growing interest in reducing energy consumption and limiting greenhouse gas emissions. This has also contributed to greater concern about the energy use of different development types.

Embodied Energy

Measurement of building energy consumption falls into two main categories: embodied and operational energy. Embodied energy is the energy consumed by all of the processes associated with the production of a good, such as a house, from the acquisition of natural resources to product delivery. This includes the mining and manufacturing of materials and equipment, the transport of the materials and the administrative functions.

Operational Energy

In urban developments, operational energy is the energy expended in the pursuit of activities carried out in urban areas, including the energy residents use to live

in their dwellings. Operational energy is dependent on occupants and may be measured by energy bills, energy metering, or by transport fuel purchases.

Operational and embodied energy demands are only a proportion of the primary energy needed to generate, refine or manufacture, and distribute energy in its various forms.

Reducing Energy Use

Bunker and Holloway (2003) suggest that it is important to measure both the operational and embodied energy of urban development to adequately assess the contribution of built form to more sustainable energy use. This is supported by an Australian Greenhouse Office study (1999) for the residential building sector, which concluded that in order to reduce residential energy usage (and therefore greenhouse gas emissions), it was important to examine both the embodied and operational energy of individual dwellings, as up to one third of the energy consumed by a dwelling in its lifetime could be embodied energy (Perkins et al. 2009).

Embodied energy can vary greatly with different construction types, while construction type can also have a marked effect on operational energy. For example, heavyweight construction systems such as brick, concrete block or rammed earth generally have higher embodied energy but, when used in conjunction with passive design in cool or temperate climate zones,

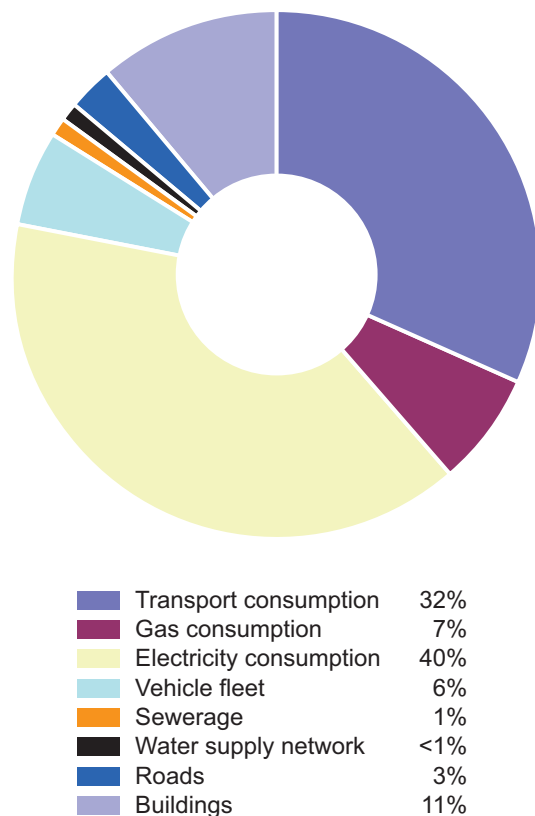


Figure 3. Average annual greenhouse gas emissions by built environment components (Troy et al. 2003)

improve thermal comfort and reduce operational (heating and cooling) energy use. In contrast, in warmer climates where the diurnal temperature range is low, lightweight construction systems, such as timber or light gauge steel, when used in conjunction with passive design generally have lower embodied energy as well as yielding lower operational energy use (DEWHA 2008).

Figure 4 shows data from the Troy et al. (2003) study that demonstrates the breakdown between different components of the built environment, and their operational and/or embodied energy use. The sections in bold are the embodied energy components (water supply network, sewerage system, roads, vehicle fleet, buildings), which at 21 per cent, are a minor component of total energy use. The remaining 79 per cent are operational energy components of the built environment. Note: the percentages given are CO₂ equivalents. In the case of the water supply network, once this figure is converted from gigajoules to greenhouse gas emissions it comprises a negligible percentage of total energy use (less than 0.5 per cent).

EXISTING AUSTRALIAN STUDIES

Australian research on the relationship between housing density and built-form energy use has taken two approaches: one is to model the potential energy use and greenhouse gas emissions of certain types of development by comparing conventional subdivision design (average net density of 10 dwellings per hectare) to traditional neighbourhood design (average net density of 25 dwellings per hectare), the other is to measure actual energy use of different housing types.

In-depth Australian studies are generally quite recent, reflecting the growing interest in this topic. See Figure 4.

Particularly relevant is research by Troy, Holloway, Pullen & Bunker (2003) and Myers, O’Leary and Helstrom (2005). More recently Rickwood (2009a & b) has provided further analysis of existing research together with original research, while Perkins, Hamnett, Pullen, Zito and Trebilcock (2009) have expanded on research by Perkins (2002) to include additional analysis of apartment buildings and embodied energy use, as a point of comparison with low density detached and medium density dwelling types.

KEY DIFFERENCES BETWEEN THE STUDIES

The studies provide slightly different levels of focus and detail. The key differences include:

1. energy use measurement
2. Unit of measurement
3. Sample size and composition
4. Definition of density
5. Variable selection

Energy Use Measurement

Earlier studies typically concentrated on operational energy, whereas more recent studies have expanded to include both operational and embodied energy through the use of modelling tools.

Embodied energy can comprise up to one-third or more of the life cycle energy of a building, but may vary considerably depending on a number of factors including the building type, its estimated life and energy-efficient features, and climatic conditions (Perkins et al 2009). As the operational energy efficiency of houses and appliances increases, embodied energy becomes increasingly important (DEWHA 2008b).

Author(s) and Year	Housing Density Considered	Energy Type Measured	Built Environment Coverage	Sample Size
Troy, Holloway, Pullen & Bunker (2003)	Low, medium and high	Operational and embodied	Transport, buildings and infrastructure	7 Census Collection Districts (approx.1540 dwellings)
Myors (2005)	Low, medium and high	Operational	Buildings	41 multi-unit buildings (3670 apartments)
Perkins, Hamnett, Pullen, Zito and Trebilcock (2009)	Low, medium and high	Operational and embodied	Transport and buildings	41 apartments compared to 164 detached dwellings and 48 townhouse dwellings
Rickwood (2009)	Low, medium and high	Operational and embodied	Transport and buildings	Modelling analysis on building forms

Figure 4. Overview of key Australian studies

Building Type	Description	ABS Functional Classification of Buildings
High-Rise	Residential apartment buildings 9 or more storeys high	High density
Mid-Rise	Residential apartment buildings 4–8 storeys high	High density
Low-Rise	Residential apartment buildings up to 3 storeys high	High density
Townhouse & Villas	2 or more attached dwellings with common or shared facilities (e.g. car-parking)	Medium density
Detached	2 or more detached dwellings with common or shared facilities (e.g. car-parking)	Low density

Figure 5. Building type description (Myors 2005)

Operational energy is impacted by human behaviour, and therefore two identical buildings may have very different energy use profiles, depending on their occupants. Unless studies isolate occupant behaviour, it can be difficult to attribute differences in energy use to physical characteristics alone. Of the Australian studies cited, only Perkins et al. (2009) and Rickwood (2009), consider occupant characteristics, by controlling for major household demographic and income variables.

Unit of Measurement

Another key variation when comparing different studies is the unit of measurement. Most studies measure energy use either per household or per capita, but do not always consider both. Measuring energy use per capita removes differences in energy use that occur due to household size (Tarlo 2002). However it does not account for the fact that there is a ‘fixed overhead’ related to the first occupant of a home bringing a fridge, TV, hot water system and a need to heat or cool a space, while extra people do not have as much need for energy, as the extra energy used for a bigger fridge or heated area is relatively small. Without an alternative unit of measurement, or a means of adjusting for these factors, it is most appropriate to show results as both per capita and per household measurements and then compare the results.

Sample Size and Composition

Sample size and composition also differ markedly between the studies selected. In most instances the sample size is not large or comprehensive enough to be considered statistically representative of the population or city in which it is based. However as Myors et al. (2005) state, ‘while not statistically representative the results point to general trends’. Therefore the results should not be discounted, but rather treated with caution when drawing conclusions.

The composition of samples also differs between studies. Typically the studies compare low density to medium or high-density development. However the selection of samples and their exact characteristics differ significantly. The comparison of density in these studies is generally assessed according to dwelling type, such as detached dwelling, townhouse or high-rise.

Definition of Density

The studies considered utilise sample sets that concentrate on the urban form or housing density at a micro level. That is, they consider density from the perspective of a subdivision, group of buildings or as individual buildings. Typically the studies compare low-density to medium or high-density development. None of the studies consider density at a macro, citywide scale – such as by measuring dwellings per hectare at a city or regional level.

The Australian Bureau of Statistics Functional Classification of Buildings (ABS 1999) provides a good indicator of how housing density can be defined at the micro level, and classes residential dwellings into three broad types: houses; semi-detached, row or terrace houses, townhouses, etc; and flats, units or apartments. These three dwelling types may be roughly interpreted to align with low, medium and high density housing respectively. However, as Figure 5 indicates, the description of building type given by Myors varies from the ABS definition, and also differs to that used by Perkins and Troy et al.

Selection of Variables

Identifying the numerous interrelated variables that may impact on residential density and energy use is difficult and can affect research findings. As Bunker and Holloway (2003) highlight, one of the main problems with energy use analysis is the multi-co linearity between many of the variables being examined. For example, household expenditure on domestic fuel, power and transport increases with income, but is also correlated with the average age and size of the household. Therefore there is a risk in making assumptions about the relationship between variables, particularly if not all relevant variables have been included in the analysis.

Another risk in variable selection is the tendency for researchers to emphasise either the nature of the household or the character of the dwelling as the main determinant. This is not helped by the lack of detailed information at the individual household level about the energy consumption, or the physical characteristics of the buildings and the characteristics of its occupants (Bunker and Holloway 2002).

KEY FINDINGS OF THE STUDIES

As the foregoing has outlined, the four main studies differ in several respects, including their consideration of housing density, measurement of energy, built environment coverage and sample size, and therefore can only be used to indicate general trends.

Taking these factors in account, the key findings of the studies include:

- Combining the urban form characteristics of dwelling type (apartments) and centrality/density (city centre location) is not sufficient to guarantee lower in-house energy consumption or emissions (Perkins et al. 2009).
- On a per capita basis, inner-city Adelaide apartments were shown to have dwelling operation and embodied energy use significantly higher than either outer-suburban (low density) or inner-suburban (medium density) locations. See Figure 6.
- Townhouse/villa developments had the lowest greenhouse gas emission levels compared to other dwelling types when measured per household or per capita (Myors et al. 2005). See Figure 7.
- High-rise developments in Sydney had higher greenhouse gas emissions per person than detached dwellings or townhouse/villas. This is attributed to the energy consumption of common areas such as lifts, corridors and pools and the lower occupancy rates of apartments (Myors et al. 2005).
- When greenhouse gas production is expressed per capita, the differences in operational energy use are less significant between inner and outer suburbs because of the larger size of households in the outlying suburbs (Troy et al. 2003). See Figure 7.
- Operational energy use in low-rise attached

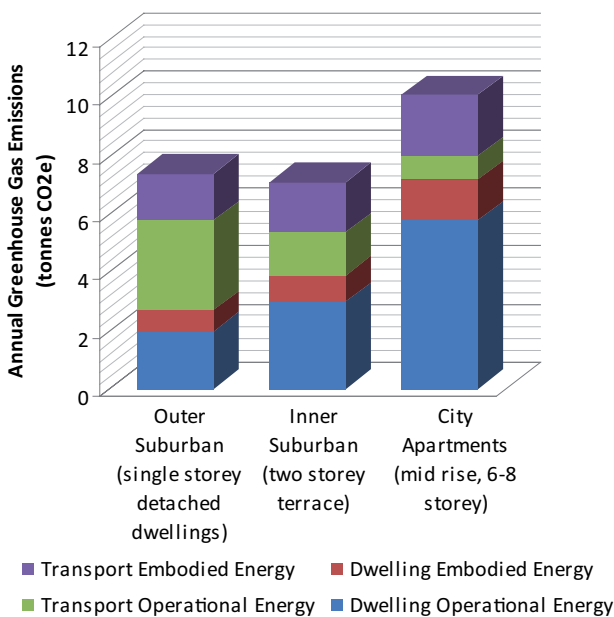


Figure 6. Annual greenhouse gas emissions per capita (Perkins et al. 2009)

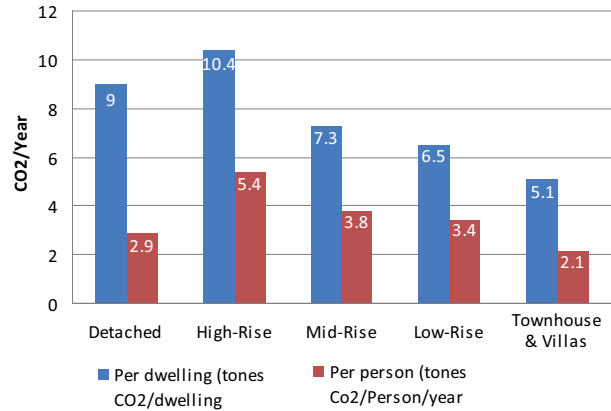


Figure 7. Comparison of per dwelling and per capita data for CO₂e emissions (Myors et al. 2005)

dwellings, after controlling for other factors, is estimated to be 15 to 20 per cent per cent lower than detached dwellings with the same number of bedrooms (Rickwood 2009).

- Analysis of possible ratios of embodied energy for different building forms suggests that low-rise attached dwellings (i.e. townhouses) have the lowest embodied energy, followed by detached houses and then apartments (Rickwood 2009).
- Appliance ownership, household size, dwelling size and dwelling type all affect energy consumption, when controlling for major household demographic and income variables (Rickwood 2009).

SUGGESTIONS FOR FURTHER STUDY

The weaknesses identified in existing studies indicate areas where future research could be improved or extended. In particular:

- Increased sample size and composition
- Variable selection, including the inclusion of social characteristics and identifying co linearity
- Influence of the built form on embodied energy and identification of the optimal density level where embodied energy is minimised

If consolidation of urban environments is to be pursued in Australia, then solid cohesive research is required to quantify the performance of existing housing. Defining the characteristics of sample sets (including social characteristics), increasing sample sizes, and ensuring future studies include embodied energy and infrastructure are all steps that would contribute to more germane research in this area.

Without a cohesive approach, it will continue to be difficult to measure the effect of increased housing density on Australia's energy use and ecological footprint.

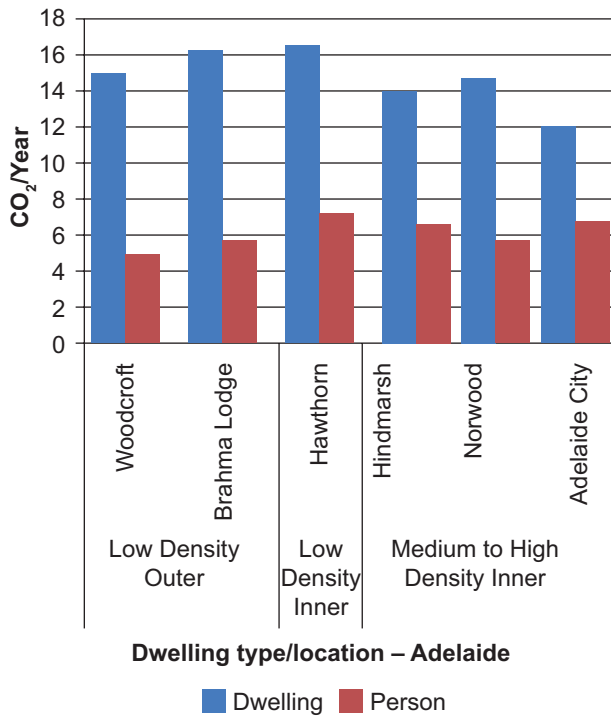


Figure 8. Greenhouse gas emissions (operational energy) by case study area (Troy et al. 2003)

CONCLUSION

Based on the existing research it appears there is a relationship between housing density and energy use, however the relationship is not collinear and is impacted by other variables.

The general evidence indicates that while increasing housing density may reduce transport energy use when combined with other elements such as employment density and activity intensity, it does not automatically result in decreased operational energy use for buildings.

The general trends indicated are that:

- Inner-metropolitan, medium-density housing (i.e. townhouse and villas) generally consume less operational energy per household than inner-city apartments.
- Outer-urban or low-density areas are generally shown to have a lesser energy use when measured on a per capita rather than per household basis, due to the greater household sizes in outer low-density areas.
- High-density development generally consumes more operational energy than either medium, or low-density development. This is predominantly due to the energy consumption of common areas, but also may be impacted by the type of conditioning system (separate or centrally provided), and the energy fuel type (e.g. gas or electric).

The research indicates that planning, design, and construction decisions should give greater consideration to the energy sources and energy provision for developments if operational energy, and hence greenhouse gas emissions, are to be reduced.

The research shows that far from automatically resulting in reduced built-form energy consumption, high-density housing in fact contributes to higher built-form energy use than low or medium-density housing. Therefore designers and policy makers should consider the following measures for multi-unit developments to increase their energy efficiency:

- Increase the use of natural lighting to corridors, stairwells and car parks
- Provide low-wattage lighting options in areas that require electrical lighting
- Provide naturally lit, open stairwells as an alternative to using lifts
- Give consideration to the energy use of common areas
- Consider the need for ‘luxury’ additions such as inground pools, spas etc. If including these, consider the fuel type used to heat them, with a preference for no or low-emissions fuels such as solar.

With attention to the design and energy efficiency of apartments, the research suggests that this type of dwelling has the potential for substantially lower emissions, in addition to reduced transport energy use through urban consolidation.

REFERENCES

ACT Planning and Land Authority, 2004, *The Canberra Spatial Plan*, ACT Government, Canberra

Australian Bureau of Statistics (ABS), 1999, *Functional Classification of Buildings*, Australian Bureau of Statistics, Canberra

Australian Bureau of Statistics (ABS), 2004, ‘Housing and Lifestyle: High Rise Living’ 4102.0 - *Australian Social Trends*, Australian Bureau of Statistics, Canberra

Australian Bureau of Statistics (ABS), 2005, ‘Australian home size is growing’, 1301.0 - *Year Book Australia*, Australian Bureau of Statistics, Canberra

Australian Bureau of Statistics, 2009, ‘Household Income and Income Distribution’, 6523.0 *Australia 2007-08*, Australian Bureau of Statistics, Canberra

Australian Greenhouse Office, 1999, *Australian Residential Building Sector Greenhouse Gas Emissions 1990-2010*, Australian Government, Canberra

Bunker, R and Holloway, D, 2002, ‘How Do We Use Energy In Our Homes – To Suit Buildings Or Behaviour?’ *Issues Paper 13*, Urban Frontiers Program, University of Western Sydney, Sydney

Bunker, R and Holloway, D, 2003, ‘Improving Sustainability in Development Planning and Control’, *Australian Planner*, 40(3), pp.31-34

Department of Planning and Development (DOPD), 1993, *Greenhouse Neighbourhood Project*, Environmental Protection Authority, Energy Victoria

Department of the Environment, Water, Heritage and the Arts (DEWHA), 2008, *Australian Residential Building Sector Greenhouse Gas Emissions 1986-2020*, Australian Government, Canberra

- Department of the Environment, Water, Heritage and the Arts, 2008, *Your Home Technical Manual - Fourth Edition*, Australian Government, Canberra
- Energy Victoria et al., 1996, *Urban Villages Project: Encouraging Sustainable Urban Form - Summary Report*, pp1-26 & 96-107
- Gray, R, Gleeson, B and Burke, M, 2008, *Urban Consolidation and Household Greenhouse Emissions: Towards a Full Consumption Approach*, Urban Research Program, Griffith University, Brisbane
- Myors, P, O'Leary, R and Helstroom, R, 2005, 'Multi-Unit Residential Building Energy and Peak Demand Study', *Energy News*, Vol.23, No.4, December 2005
- Newman, P and Kenworthy, J, 1999, *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press, Washington D.C., USA
- Newton, P, 2001, 'Human Settlements Theme Report' Australia State of the Environment Report 2001, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Australian Government, Canberra
- Newton, P, 2006, 'Human Settlements Theme Report' Australia State of the Environment Report 2006, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Australian Government, Canberra
- Newton, P, Flood, J, Berry, M., Bhatia, K., Brown, S., Cabelli, A., Gomboso, J., Higgins, J., Richardson, A. And Richie, V, 1998, *Environmental indicators for national state of the environment reporting – Human settlements*, Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra
- Perkins, A, 2002, 'The influence of urban form on life cycle transport and housing energy and greenhouse gas emissions', *PhD Thesis*, University of South Australia, Adelaide
- Perkins, A, 2003, 'How Significant an Influence is Urban Form on City Energy Consumption for Housing and Transport?' *Conference Paper for State of Australian Cities National Conference*, Parramatta
- Perkins, A, Hamnett, S, Pullen, S, Zito, R and Trebilcock, D, 2009, *Urban Policy and Research*, 1476-7244, Vol. 27, Issue 4
- Randolph, B, 2005, 'Higher Density Communities: Current Trends and Future Implications' presented at the *Strata and Community Title in Australia for the 21st Century Conference*, Faculty Built Environment, UNSW, Sydney
- Rickwood, P, 2009, 'Residential operational energy use', *Urban Policy and Research*, Vol.27, Issue 2
- Rickwood, P, 2009, 'The Impact of Physical Planning Policy on Household Energy Use and Greenhouse Emissions', *Thesis submitted for award of Doctor of Philosophy*, Faculty of Design, Architecture, and Building, University of Technology, Sydney
- Royal Melbourne Institute of Technology (RMIT), 2003, 'Re-Imagining the Australian Suburb'
- Scheurer, J, 2001, PhD Thesis 'Chapter 10 - Compact City Policy: How Europe Rediscovered its History and Met Resistance' in *Urban ecology, innovations in housing policy and the future of cities*, Murdoch University, Perth
- Sustainable Solutions, 1998, *Strategic Study of Household Energy and Greenhouse Issues*, Australian Greenhouse Office, Australian Government, Canberra
- Tarlo, K, 2002, *Urban Consolidation Challenge – Review of Environmental Impacts*, Institute for Sustainable Futures, University of Technology Sydney
- Troy, P, Holloway, D, Pullen, S and Bunker, R, 2003, 'Embodied and Operational Energy Consumption in the City', *Urban Policy and Research*, 21(1)
- Urban Frontiers Program (UFP), 2003, 'Submission by Urban Frontiers Program' *Inquiry into Sustainable Cities 2025*, House of Representatives Standing Committee on Environment and Heritage, Australian Government, Canberra

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