Sustainable housing in Metropolitan Adelaide: a study on residents' perception

Li Meng, School of Natural and Built Environments, University of South Australia

Rita Yi Man Li, Sustainable Real Estate Research Center / Department of Economics and Finance, Hong Kong Shue Yan University, Hong Kong / School of Natural and Built Environments, University of South Australia

Xiaodong Huang, University of South Australia

Jian Zuo, School of Natural & Built Environments, University of South Australia

Abstract

The design, location and materials of housings affect its sustainable operation performance. The South Australian government in recent times has promoted middle to high- rise apartments in preference to the traditional detached house style in metropolitan Adelaide to minimise household energy consumption. Nevertheless, change in style has limited success and there is a lack of sufficient information for policy makers and residents to implement. This paper studies the perception of the public and provides three different scales to explain the pros and cons of these two types of house style. The results show that middle to high-rise apartments should be encouraged. It concludes that it is important for us to consider using energy efficient materials to build apartments, locating apartments near public transport nodes, and providing sufficient services such as shops and schools.

Keywords: sustainable housing, apartment, detached house, resident's perception, Adelaide

1. Introduction

The world has changed over the past couple of decades with an increase in consensus that we have to reduce the exploitation of natural resources so as to relieve the adverse environmental consequences. Sustainable development, a notion that highlights the importance of co-development in economic, social and environmental aspects, is gaining weight in recent years (Li 2011; Li 2014). It is also an inevitable solution that we have to explore. As buildings in Australia account for 23 percent of the country's greenhouse gas emissions (Ministry for the Environment 2009) and energy use in residential buildings accounts for around 13 percent of total carbon dioxide (CO_2) emissions from all sources in Australia (MED, 2006), the development of green buildings which improve design, construction practices and standards is important in our built environment. In essence, all buildings should have a longer lifespan, higher energy efficiency, economical operation, and increased productivity, which leads to a healthier environment for our present and future generations.

Adelaide is one of the most liveable cities worldwide (News, 2014) and sustainable development is crucial to maintain this status. However, housing in Adelaide is widespread and low density. Private cars remain the major transport means in this city (Meng, 2013). To cope with these issues, the Adelaide 30-Year Plan (The Plan) outlines some feasible solutions on how to balance population and economic growth problems, preserve the environment and protect the heritage and history of Adelaide. The Plan seeks to do this by creating inclusive, vibrant and liveable communities, while protecting the regional hinterlands, primary industries land use, sustaining natural resources and assisting the State Government, local government and the entire community in building resilience to the risks and impacts of climate change (Government of South Australia 2010).

The Plan contains a detailed strategy to locate the bulk of middle to high-rise apartments in established areas around existing public transport networks and transit corridors to create a transit-connected city (Government of South Australia 2010, 2011). It has to be noted that in developing these middle to high- density and convenient apartments, energy efficiency is also one of the important concerns to achieve low carbon living (Sandy 2011).

As population and dwelling demand in Adelaide increases, planning for land use and residential building structure early in the conception phase is critical. Middle to high-rise residential buildings and courtyard houses will be two major types of dwelling for residents to choose; both of them comprise a variety of attributes and present challenges and opportunities with regards to adaptation and sustainability. This study aims to analyse residents' preferences on different attributes of housing with regards to sustainability, including materials, construction and built environment of middle to high-rise apartments and courtyard houses to propose solutions for sustainable residential building and urban form in Metropolitan Adelaide. The structure of this paper starts with a literature review on sustainable housing in Section 2, followed with a research method in Section 3. Section 4 provides data analysis and discussion. The paper ends with a conclusion in Section 5.

2. Literature review

In view of global climate change and environmental pollution from various industrial activities and automobiles, sustainable development has been considered as the greatest challenge in the 21st century (Sachs and Warner 1995). Sustainable development strikes a balance between the available technologies, strategies of innovation and the policies of governments (Vollenbroek 2002). It aims to enhance our quality of lives and thus allow people to live in a healthy environment and at the same time improve social, economic and environmental conditions for our present and future generations (Ortiz et al., 2009). The built environment constitutes one of the main supports of economic development and its construction has a significant impact on resources (e.g., land, materials, energy, water, human/social capital), and the living and working environment (Bourdeau 1999). The construction industry, including the relative materials industries, is one of the major exploiters of natural resources from physical and biological perspectives (Spence and Mulligan 1995).

Sustainable construction has different approaches and different priorities in different countries. The main emphasis in national definitions is on ecological impacts to the environment (Bourdeau 1999). While the building sector is not the largest contributor to greenhouse gas emissions, it is one of the fastest-growing contributors of greenhouse gases (Harle 2008). Therefore, "environmentally sustainable construction" has been listed as one of the nine key visions for the future emerging from the Construction 2020 process (Hampson and Brandon 2004), which includes the vision for industry to design, construct and maintain building structures and infrastructure to minimise the negative impacts on the natural environment – minimise waste, maximise recycling and re-use, reduce the need for non-renewable resources, and avoid land, water and air pollution so as to preserve the environment for our future generations (Hampson and Brandon 2004).

According to Bourdeau (1999), developed countries sustainable building is achieved through new developments or upgrading existing building stock. Energy efficient houses have been built in a number of communities across Sweden (Sustainable living in Sweden 2013). In developing countries, the idea of sustainable construction mainly focuses on the need to alleviate housing shortage problems where social equity is much higher on the agenda than environmental concerns. In general there is less divergence on developing a sustainable environment for our next generations (Bourdeau 1999).

The industry today recognises that environmental and life cycle analyses are needed to inform decision makers in the design and construction of infrastructure and buildings and the manufacture of material components. Some firms and organisations have already included triple-bottom-line accounting (economic, social and environmental) in their balance sheets and the trend is increasing. Current redevelopment of the built environment is slow. Urgent attention needs to be given to the continuous improvement of built assets to enhance environmental outcomes (Hampson and Brandon 2004).

2.1 Residential buildings in Australia

Energy use in residential buildings accounts for around 13 percent of total carbon dioxide (CO_2) emissions among all types of energy use in Australia (MED 2006). It is anticipated that population growth, the trend of smaller family sizes, and the desire for a more comfortable indoor environment and larger house will increase energy demand and greenhouse gas emissions from the residential buildings in Australia (Wang et al., 2010). It is therefore critical that the housing industry needs to react and participate in overall energy reduction and housing sustainability through efficient house construction and design. This environmental suitability relates to the maximisation of energy and water efficiency for specific housing markets and the varying weather conditions they experience (Bryant and Eves 2012).

There was a tightening in Building Code of Australia's energy efficiency regulation in 2003 when four-star energy efficiency was mandatorily required in Australia for all the new residential dwellings. In 2007 it was increased to a five-star rating system (Bryant and Eves 2012).

The National Strategy on Energy Efficiency was released by Australian state and territory governments in July 2009, to transform the energy efficiency of residential, commercial and industrial buildings. In the residential sector, key measures to increase the number of energy-efficient homes across Australia include (Bond 2011):

- increasing energy efficiency requirements for new residential buildings to six stars, or equivalent according to the 2010 update of the Building Code of Australia, as well as introducing new efficiency requirements for hot-water systems and lighting;
- providing information to the housing market by requiring Australian homes to provide energy, greenhouse and water performance information to buyers and renters, starting with energy efficiency in 2012;
- developing a national building framework to deliver consistency in how building energy efficiency is assessed and rated throughout Australia and for reviewing and setting stronger minimum energy efficiency standards for new and existing homes; and
- Offering financial support and information resources to homes.

The Australian Government has strived to improve the energy efficiency of existing homes by providing grants and rebates for green features, such as photovoltaic and solar hot water systems, ceiling insulation, heat pumps, rainwater tanks and grey water systems. However, as a result of some serious problems such as faulty insulation installation that resulted in loss of life, some of these programs have either been discontinued or replaced. The insulation program has been removed and the Green Loans and Green Start programs were closed in February 2011 (Bond 2011). There are two energy efficiency targets in South Australia's Strategic Plan which relate to improving energy efficiency in homes and government buildings and also to reducing greenhouse gas emissions in South Australia (Government of South Australia, 2013). One of the targets related to homes is to improve the energy efficiency of dwellings by 15 percent by 2020 (Government of South Australia, 2013). Water heating, and heating and cooling of homes use a large amount of energy and produce greenhouse gases (Bond 2011). The design of the houses must incorporate the idea of sustainable water and energy use.

Sustainable urban design is an important factor contributing to positive energy conservation outcomes. For example, the Adelaide 30-Year Plan for Greater Adelaide states that a new built form with more appropriate housing building structures in more accessible locations are needed. This underpins the creation of a new, more compact and efficient urban environment (Government of South Australia 2010). The Plan also aims to create a better environment that encourages social inclusion, giving people an opportunity to participate in social and economic activities, while reducing journey-to-work times by providing job opportunities nearby (Government of South Australia 2010). Meng, Taylor and Holyoak (2012) conducted a case study in the Adelaide North Rail Corridor to investigate people's choices of residential type and location and found that working families, especially those with children, would like to choose a house that is near transport node and services.

2.2 Middle to high-rise apartments and detached houses in terms of sustainability

Middle to high-rise residential buildings and detached houses form three primary types of dwellings that people choose to live in almost in all major cities in Asian countries and in some big cities in western countries (Niu 2004). Due to the higher density of population, middle to high-rise apartments are the only way to combat the issue of housing shortages in megacities throughout the world, such as New York, Tokyo and Hong Kong etc. Courtyard houses or detached houses are rare in the urban area of big cities as the land is too expensive. However, detached family houses are still more preferred in some lower density population countries, such as Australia, to create a spread city form which then requires more travel by private car.

Both middle to high-rise apartments and detached houses comprise a variety of attributes and present challenges and opportunities with regards to sustainability. The discourse and practice of sustainable housing is focused on the dwellings' design and the methods and materials used in the construction field (Randolph et al., 2008; Low et al., 2005). More recent sustainability in housing developments has been associated with the trend towards urban densification (SA Government, 2009). Two perspectives on the differences between middle to high-rise apartments and detached houses are: micro-scale of development and macro-scale of strategic urban development (Goodchild 1994).

2.2.1 Micro-scale

From a micro-scale point of view, material, energy efficiency and construction methods are the three most important factors to consider when we build houses in a more sustainable approach.

Materials

Construction materials related to the selection of materials such as the use of low embodied energy new materials, or the re-use and recycling of old materials. Many studies focus on energy conservation in building operation, Chen et al., (2001) claimed embodied energy used in residential buildings accounts for up to 40% of the life-cycle energy used in residential buildings, and Pullen et al., (2006) suggested reducing embodied energy lowered the overall life cycle energy consumption of homes.

Due to the vast structural differences between middle to high-rise buildings and detached houses, there is a substantial volume of steel and concrete being used in the construction of middle to high-rise apartment for structural purposes while timbers and blocks are the common materials for single storey houses. Steel and aluminium are the two most common materials used in the construction of middle to high-rise buildings. Embodied energy in steel and aluminium ranks the first and second largest in energy use which accounts for more than 75 percent of the total embodied energy in a residential building, even though the building material is concrete. The use of recycled steel and aluminium saves more than 50 percent of the embodied energy and the use of materials as alternatives to non-structural concrete walls result in significant savings. These opportunities lead to great challenges in developing novel building design concepts and innovative technologies to realise these potential savings (Chen et al., 2001).

Compared with other common building materials such as steel, aluminium and concrete, hardwood timber not only stores carbon, it uses up to 85-times less energy in processing. Concrete floor slabs uses 60 percent more energy than a timber floor, double brick walls use almost 5-times more energy than timber frame weatherboards, and an aluminium window uses 45% more energy than an equivalent timber window (Australian hardwood network, 2013). Timber frame brick veneer saves 8.8 tonnes of CO_2 per house compared with double brick construction. Carbon emissions are the highest pollutants compared to the other emissions from housing construction, which takes up as much as 93 percent of the total emissions. Figure 1 shows that the wooden type of housing construction has less environmental impact compared to a steel reinforced concrete construction as it produces 23 percent lower carbon emissions (CO_2), 7 percent lower nitrogen oxides (NOx) and suspended particulate matter (SPM), but 11 percent higher sulphur oxides (SOx) than a steel reinforced concrete construction (Gerilla et al., 2007).

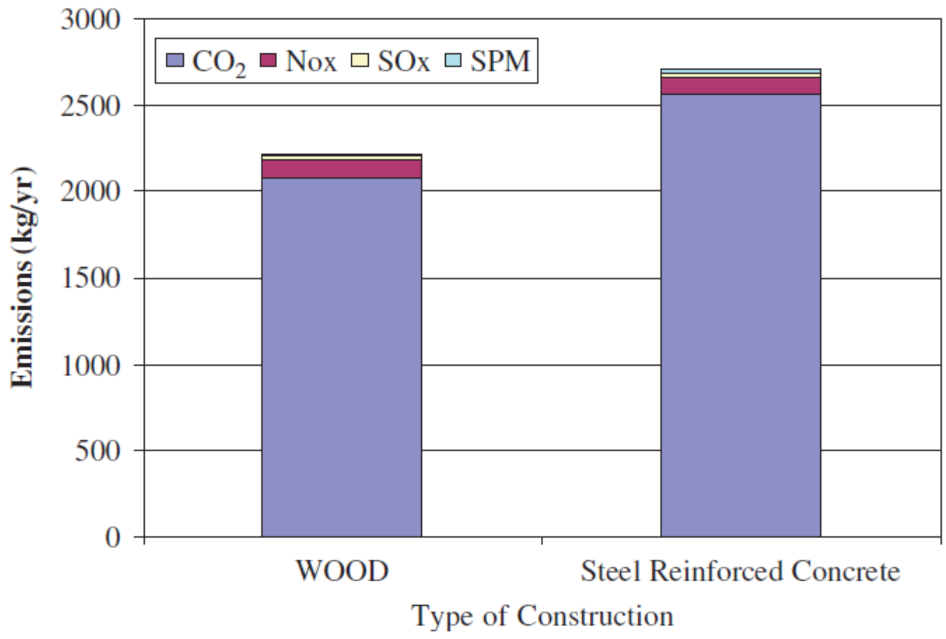


Figure 1 Total life cycle emissions for wooden and SRC type of construction

Source: Gerilla, G. P., Teknomo, K., & Hokao, K. (2007).

Furthermore, emissions from carbon pollutants in operation stage are the highest as compared to the other life cycle stages. Figure 2 shows that carbon emissions from the operation stage constituted about 79 percent of the total emissions. The carbon emissions from the other stages are only about 21 percent of the total carbon emissions. This is why energy efficiency plays a critical role in sustainable housing.

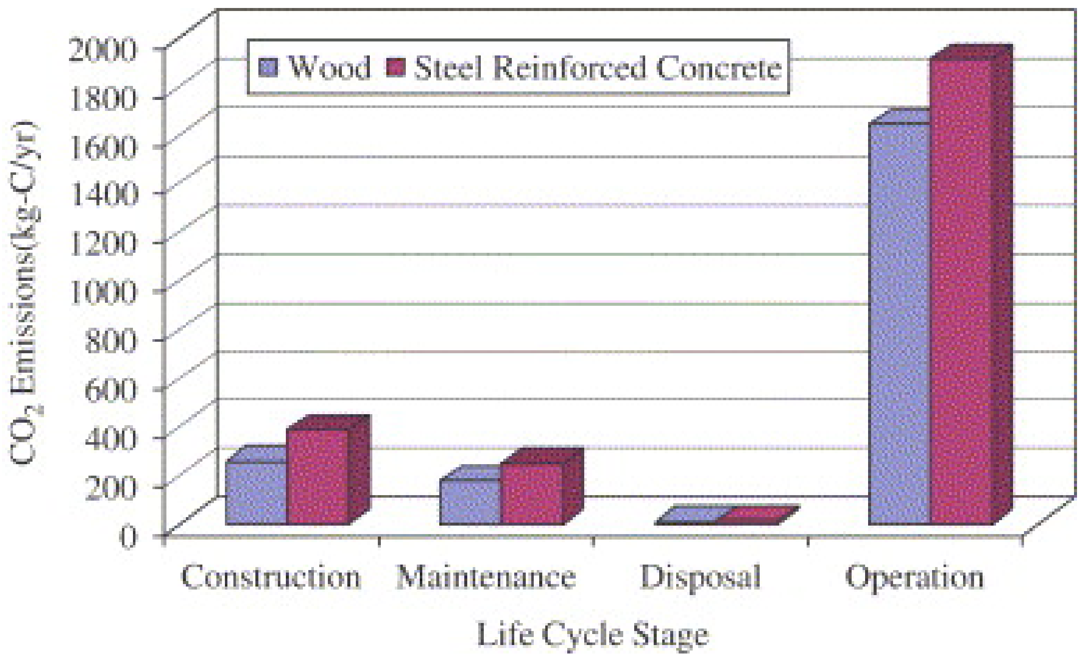


Figure 2 Total life cycle carbon emissions for each life cycle stage

Source: Gerilla, G. P., Teknomo, K., & Hokao, K. (2007).

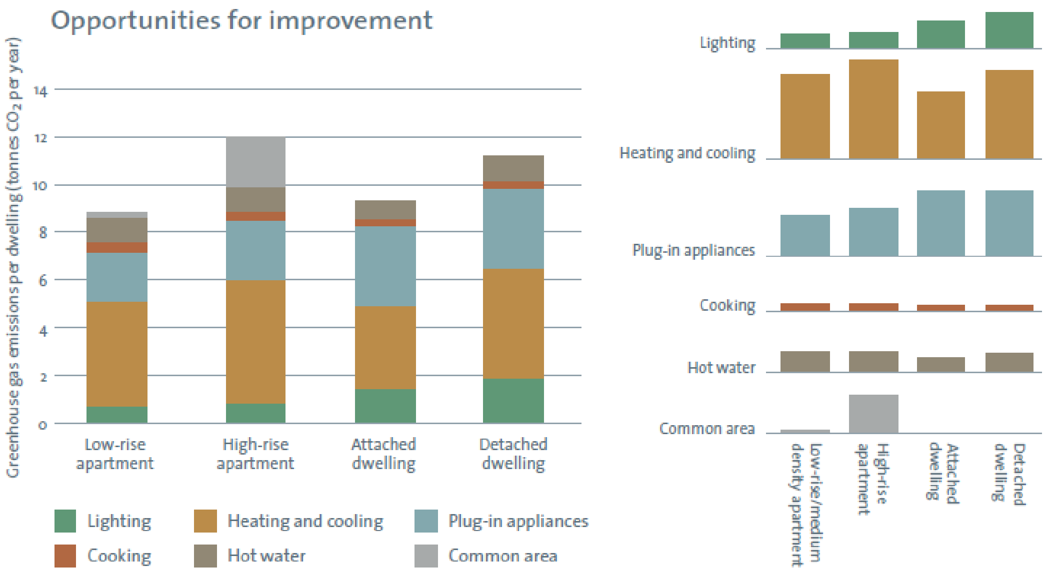
Buildings are seldom constructed from a single material, so the embodied energy of a structure depends on the number of materials used. From a material perspective, it appears that a wooden detached house is more environmentally friendly than a reinforced concrete apartment building in terms of greenhouse gas emissions. So far, a wide range of materials have been invented to improve energy efficiency of a home and reduce embodied energy, such as gypsum plaster and plywood.

Energy efficiency

Carbon emissions from the operation stage account for almost 80 percent of the total emissions. Both active and passive measures reduce energy consumption and greenhouse gas emissions of dwellings. It represents one of the most important areas where housing contributes to sustainable development (Kibert, 2008; Larsen et al., 2008).

Reports have stressed that low-rise apartments are the most important carbon-efficient buildings (SA Government 2009) (see Figure 3). The impact of greenhouse gas emissions between different types of developments can be demonstrated as follows:

- High rise apartments have the highest heating and cooling load (12.23 tones equivalent carbon dioxide [CO_2-e]) and additional emissions from a range of shared services, such as lifts, air-conditioning, car parks, pools and gyms (2.04 tonnes CO_2-e) per dwelling.
- Low-rise apartments and attached dwellings have the lowest heating and cooling load 9.189 tonnes CO_2-e) and lower emissions from the range of shared services (0.7 tonnes CO_2-e) per dwelling.



Source: Arup, Carbon modelling, prepared for the Department of Planning and Local Government (DPLG), Government of South Australia, in Background technical report, 2009, <www.plan4adelaide.sa.gov.au>.

Figure 3 Greenhouse gas emissions by dwelling type

Source: Government of South Australia (2009)

The greenhouse gas emissions between these two forms of development differ because of the additional energy requirements of shared services. Middle to high-rise apartment buildings have more complex systems than single family dwellings in terms of energy saving. Given that water heating and cooling of homes uses the most energy and produces the most Green House Gas Emissions (GHGe), these areas should be focused on in house design (Bond 2011).

In modern times, central systems have been applied to most middle to high-rise buildings, as they have higher efficiencies and lower pollutant emissions. However, in apartment buildings, we must consider the use pattern and occupants behaviour. The utilisation factor of air-conditioning varies, which means central systems may operate at low-partial load conditions most of the time. Thus the actual efficiency is far lower (Niu 2004). Concerning heating, Many European countries switched from a central oil-fired boiler to individual gas-boilers, centralized exhaust stacks are provided in middle to high-rise flats. This change occurred because new domestic boilers are designed with high efficiencies (Niu 2004).

The problems may be more complicated when we consider air conditioning systems. Window- and split-type air conditioners have far lower efficiency than central water-cooled chillers, however they still dominate residential air-conditioning as the temperature can be adjusted according to individuals' needs and they have a lower maintenance cost. The noise and heat problems are also obvious (Bojic et al., 2001; Chow and Lin, 1999). For middle to high-rise residential buildings, the use of a centralised chilled-water supply, individual household controls and metering of its flow rate and in-let and out-let temperature differences may be the best system (Niu 2004).

Construction method

Construction methods and techniques have the potential to improve affordability and environmental sustainability (Pullen et al., 2010). Time, cost and resource use are some of the most important production performance issues in the construction industry (Tam et al., 2002). There are many modern methods of construction (MMC) or non-traditional methods which are used for residential buildings especially for middle to high-rise apartments. MMC has been defined as a process to produce more, better quality homes in less time (Fawcett et al., 2005). New construction technology and effective construction methods affect time, labour requirements and costs. The empirical research shows that MMC are most effective in shortening construction time. Further, new construction technology can also reduce the requirements for skilled tradesmen of which Australia is experiencing shortage. However, construction costs may increase with shorter construction duration (Tam et al., 2002). Examples of this type of innovation include prefabrication and internal thermal massing.

Regarding detached houses, due to its relative simple structure and construction process, traditional construction methods are used in most projects. Brick veneer construction is the most popular building method in Australia when building a single family dwelling, with a wood or metal frame to support the roof, panelling on the inside walls and a skin of bricks on the outside. This is because compared to the traditional double brick house, a brick veneer house is cheaper and faster to build without sacrificing the advantages of a solid brick house (Powerhouse Museum).

2.2.2 Macro-scale

Sustainable housing does not only emphasise the building structure itself, but considers the complete urban development process. Generally speaking, density and urban form, affordability and transport and land use are the three most important factors in building sustainable houses with a more sustainable approach on a macro scale.

Density and urban form

Density is the most important issue from a macro perspective. Density refers to the density of land use and the amount of land required for urban development (Goodchild 1994). Although there is no consensus on its definitions, housing density generally refers to the number of housing units in a given area (Forsyth 2003). With an increase in population worldwide, we are now facing the challenge of urban sprawl. Cities and urban areas emit up to 75 percent of the world's greenhouse and a better planned urban form is needed.

Most cities are formed by a mixture of different density levels in different residential areas. There is a general consensus that middle to high-rise apartments should be located in the inner city as they accommodate more residents than a detached building which increases population, while low-rise flats and detached family houses are located in the city fringe and suburban area. In general, an increase in urban density improves sustainability (Rickwood et al., 2008). From this perspective, middle to high-rise buildings are a more sustainable solution for urban development. However, Perkins et al. (2009) have suggested that high density development does not guarantee lower per capita greenhouse gas emissions. This is mainly because of the lower occupancy rates and higher emissions arising from operational and embodied energy consumption, which represents a new research topic in sustainable urban development.

It is suggested that middle to high-density housing estates have the advantages of avoiding the problems associated with the extremes of low suburban density cities such in the United States and many Asian cities. Some researchers have suggested a degree of caution is advisable lest the desire to increase densities goes too far (Goodchild 1994).

Australian cities share similarities with the US in terms of low density and wide-spread housing areas (Buxton, 2000; Mees, 2000). Therefore, to avoid waste and a sense of fragmentation due to dispersal of population and economic activity, governments need a new built form that will provide more appropriate forms of housings, such as semi-detached houses and apartments, in more accessible locations with convenient services (SA Government 2009; Meng, 2013). A more compact and efficient urban environment has been promoted by governments in recent years (Goodchild 1994).

Affordability

Affordable housing is housing that is reasonably adequate in standard and location for a lower or middleincome household which allows them to meet the needs of their other daily expenses (National Summit on Housing Affordability, 2006).

Demand for affordable housing remains high and its provision is probably more important than ever. While there are many economic and social determinants of affordability, including the costs of running a home and associated travel over the life of the household, the most widely used measure in Australia (used by, for example, Australian Government, 2008; Beer et al., 2007; Berry et al., 2004; Disney, 2007; Gurran et al., 2008; Yates et al., 2007; Yates et al., 2008) is the '30/40 split' which suggests that housing costs should not exceed 30% of household income for the bottom 40% of income groups. Knowing average incomes, it is then possible to calculate an affordable house cost in terms of purchase price and rent (such as Department for Families and Communities) and such figures may determine eligibility for certain affordable housing schemes (as in City of Salisbury, 2009).

There are many tensions associated with price mechanisms. Buying a house could be the most important decision in a person's life in view of the large sum of payments required such as costs of housing, stamp duty and council fees. Indeed, the only way to find affordable housing may be restricted to poorly located areas. In Adelaide, some affordable houses are developed in fringe areas where public transportation is poor and households must buy a car to travel, but they not to mention environmental features or innovative technologies (Yates et al., 2008).

Transportation and land use

The energy used in building operations is only part of the total energy consumption in the urban environment. The energy used in transportation is also significant (Perkins et al., 2009). Hence, concepts of urban form involve both the spatial distribution of dwellings and their built morphology since the former affects energy consumed for personal transport and the latter affects the energy used in households (Rickwood et al., 2008).

Whilst urban density may affect transport energy consumption, it also implies different types of built form. In most cities around the world, apartments are normally built in the CBD area or dense population areas, while detached houses are built in fringe areas. High density development can enable more facilities to be located within a shorter distance of residents which may enable daily activities to be reached by walking, cycling or public transport. Both transport and built form are factors that should be considered in the analysis of urban energy consumption.

When we consider carbon emissions arising from operational energy usage, middle to high-rise apartments contribute more than detached houses. However, the total delivered energy usage of apartment householders was lowest and that of the outer suburban householders, most of them live in a detached family house, was highest due to a high level of transport operational energy consumption resulting from car usage (Perkins et al., 2009). Figure 4 shows that a substantial proportion of people living in suburban areas chose car as their travel mode, while a large proportion of people living in the city centre prefer walking.

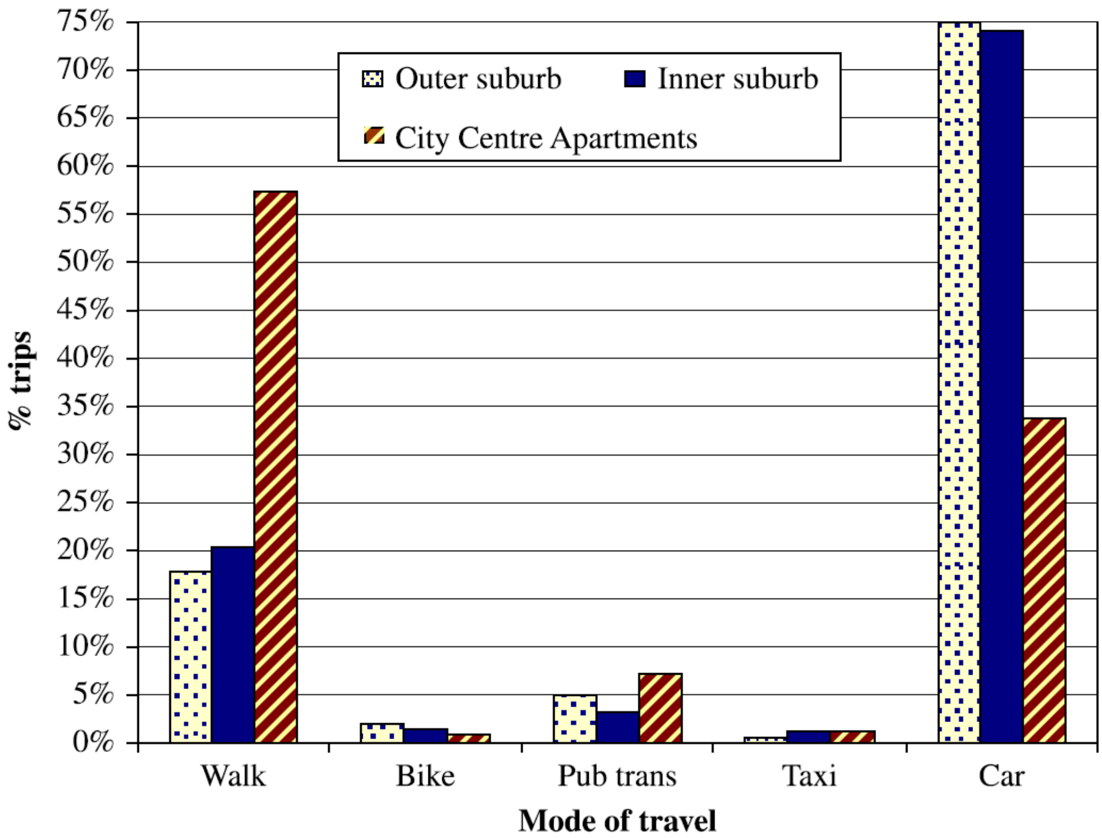


Figure 4 Proportions of trips by mode - comparison of the three samples

Source: Perkins, A., Hamnett, S., Pullen, S., Zito, R., & Trebilcock, D. (2009).

Reducing car dependency in low density areas requires a number of policy measures such as improved public transportation, localisation of services and increase residential density around transportation hubs. That is why the government plans to build new houses close to existing and planned transport infrastructure in the Adelaide 30-Year Plan. Moreover, when properties are located close to public transportation, it has a positive impact on property value. The empirical research shows that a location close to a rail station would be desirable to renters as rent plays a vital role in property valuation and decisions about new construction (Benjamin and Sirmans 1997).

One of the major drivers for middle to high-rise apartments is to minimise land use and provide more daily services within walking distance such that the needs for driving and energy usage can be reduced (Chileshe et al., 2012). Besides minimising the impact of carbon emissions on the environment, introducing a residential population into the area of a commercial or industrial zone can significantly reduce the use of automobiles. Nowadays, the central business districts (CBD) in many cities allow a combination of residential, retail, office, commercial and civic uses. Such arrangements do not only promote visual interest and variety in towns and city centres, it also enhances the value of buildings with special architecture interests which attract young people to move in. (Goodchild 1994).

3. Research methodology

The research is to study the general public's perception on sustainable building in Metropolitan Adelaide, a questionnaire survey is an effective and viable way to collect data. As an internet survey is both cost and time efficient to deal with a sizeable sample size and respondents from different geographical areas (Wilson and Laskey 2003), we distributed the survey via this method using Survey Monkey online. The questionnaire consisted of 22 questions is to assess the general public's awareness of sustainability and their preferred type of dwelling in Metropolitan Adelaide. The study used stratified sampling method. The survey invitations contained an internet link were sent both via email to some of selected social contacts, and by handouts to some randomly selected households' mailbox and people in public places. 53 online responses had been received in two months from 200 invitations (with 27 percent of response rate), including 4 incomplete questionnaires and 2 respondents who moved to other states. This resulted in the total number of valid responses of 47 with various age and income levels which is similar to that of the proportion of Adelaide.

The questionnaire had been designed based on the literature review according to micro and macro scales of housing sustainability and residents' socio-demographic information. It questions the respondents' preferences for a sustainable lifestyle when they choose a new home and their awareness of the mandatory legal requirements for all new houses, their current home characteristics, such as ownership, type of dwelling, number of bedrooms and car parking, and the household composition. It also includes

- the aspects of factors that have been identified as having influence on buying a new home
- the materials they would use when building a house
- actions that have been identified to relieve household climate change pressure
- the likelihood of adopting the listed behaviours or actions
- payment for a sustainable home as well as the reasons for not undertaking them are included
- preferred type of travel mode and distance to key locations from home
- socio-demographic questions are included at the end of the survey.

4. Data analysis and discussions

More than half of participants (58 percent) are aware of the current mandatory requirements for new houses. However, the majority (37 percent) are aware that the new housing sustainability policy but they are not going to apply, while more than 40 percent said they had no idea about the requirements

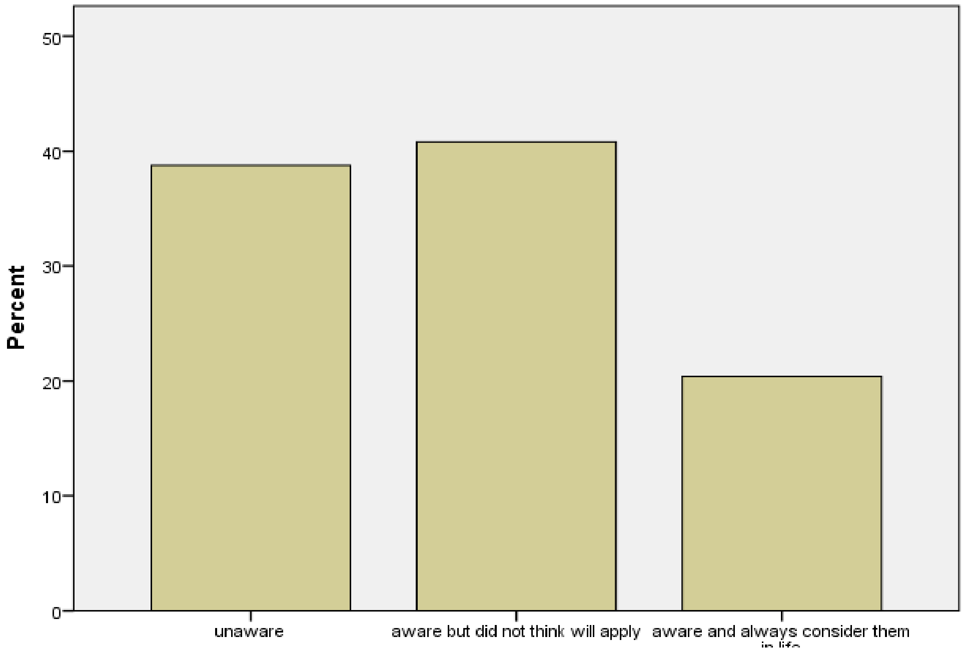


Figure 5 Public Awareness of the Mandatory Requirements

(Figure 5).

In terms of the ownership of property, more than half of the participants (57 percent) rented their housing units, while 30 percent of participants own a property. Over half of the respondents (50 percent) currently live in a detached house, 18 percent live in a semi-detached house or a townhouse, 28 percent of participants live in an apartment or flat and 2 percent live in other dwellings. With regards to the preferred type of dwelling, the majority of the respondents (67 percent) chose a detached house, while 16 percent and 13 percent picked a semi-detached and apartment respectively. This number of dwelling type appears to be in line with the latest 2011 Census of Australia that 80 percent of houses in South Australia were detached houses, 10 percent were semi-detached, row or terrace houses, townhouses, 9 percent were flats, units or apartments and less than 1 percent were other dwellings (ABS 2013). This is because of the low population density in Adelaide and the history of development as single level development. The number of high rise apartments is increasing in Adelaide CBD area, however, such development is slow and encounters difficulties. With regards to sustainability, it is advised that major capital cities should be built in a more compact form with easy access to public transport in the future.

The majority of the homes had either two (35 percent) or three bedrooms (37 percent). Over half of all the homes (51 percent) had one car park available and 30 percent had two car parks. These figures are in line with the average of three bedrooms per dwelling in South Australia. However, most of the participants (82 percent) wish to have a bigger home with three or more bedrooms and over half of them (52 percent) agree that two car parks are needed as the ideal home. In terms of household size, 35 percent of respondents have two persons, and 32 percent of three persons compared with 33 percent for one person, respectively. These figures are in line with the average of 2.4 people per household in South Australia. The figures indicate that the average number of bedrooms per household is more than the average household size. It is understandable that people would like to have extra bedrooms to accommodate more people in reasonable comfort. Moreover, households may put these spare rooms to various uses, such as a study room, office or store room. However, it is no doubt that more bedrooms mean extra energy consumption not only during the occupation stage, but also more materials containing embodied energy would be consumed during construction.

According to these figures, we understand that there are still many people unfamiliar with the new housing regulations and that awareness of sustainability is not very high. Even though many of them know the new requirements of sustainability, they do not put them into practice. To build a sustainable city, we cannot only rely on the government initiatives, the public has to understand the importance of sustainability and show their support to achieve this common goal. Secondly, we found that the trend to smaller household sizes and larger homes has become a barrier to reduce impacts on the environment. Finally, the study found that buyers were more concerned about the price of the property and its location than the energy rating of the property.

4.1 Micro-scale

Figure 6 shows that brick (45 percent) is the most popular material for building a house frame structure, while steel frame and concrete are ranked second (20 percent) and third (18 percent). Only 12 percent of the participants choose a timber frame for their preferred house structure even though timber has been proven to be more environmental friendly than other common construction materials such as steel, aluminium and concrete in terms of greenhouse gas emissions.

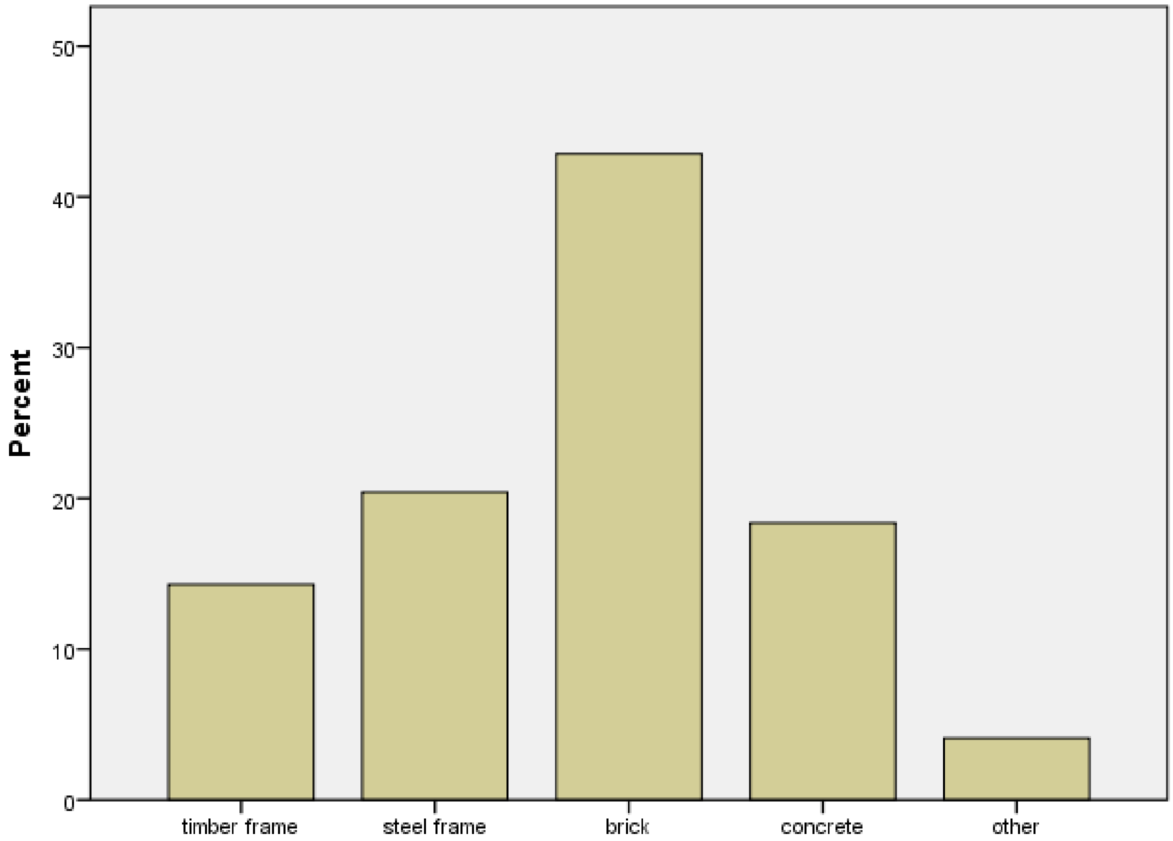


Figure 6 Preferred Building Frame Structure

The figures indicate that people prefer to choose brick for their home since most current houses were built in either brick veneer or a double brick structure. Although a double brick structure has better thermal mass, brick veneer is more popular as it is more affordable and faster to build. The advantage of brick veneer is that it saves energy through the use of an internal timber frame reducing the amount of embodied energy at the construction stage. To alleviate the issue of energy usage during the occupation stage, a new form of construction called reverse brick veneer has been developed where bricks are on the inside of the structural framing of a home and contributes to the heating and cooling efficiencies of the building.

Concrete and steel are used frequently for high rise apartments, and in Adelaide some detached family houses also choose a steel frame as a building envelope despite the high material cost. Steel has high embodied energy and its production can emit harmful substances. Additionally, the production of the steel needed for reinforcement of concrete has a major environmental impact.

From a material perspective, even if timber has been proven to have the least impact on the environment, quite a large number of people still choose other materials which contain high embodied energy such as steel as major structural materials. This may be due to the lack of information about embodied energy. Using recycled materials should also be promoted within the general public.

From a range of actions that have been identified as having a significant effect on household greenhouse gas emissions, respondents were asked to indicate the likelihood of them adopting the listed actions: already doing; likely to do; unlikely to do. The first 9 actions were regarded as no cost actions, while the last three belong to cost actions.

More than 50 percent of the participants have engaged in no cost actions, such as turning off all appliances when they are not in use; turning lights off when they are not in the room, using natural lighting where possible and drying clothes using a clothesline rather than electric clothes dryer. Even though the first 9 actions do not involve any cost, many participants still ignore them. This demonstrates that habit and behaviour are important obstacles to achieving the goal of environmental sustainability. Most of the participants who did not take actions are men, while most of the women tend to be more aware of the need to save energy. The benefits of energy conservation and the risks from climate change should be widely reported in mass media to increase sustainable awareness among the public. The last three actions were regarded as cost actions, requiring people to spend money to upgrade their home to reduce greenhouse gas emissions. Not surprisingly only a small portion of respondents were already implementing these actions compared to the zero cost actions. Less than 10 percent of participants have already installed a solar hot water heater, which is the lowest percentage among the actions which have been enacted.

A positive sign of rising sustainable awareness is that the majority of respondents (75 percent) are willing to invest extra money into upgrading a home in order to reduce their energy bills. Most of the participants would like to spend no more than $10,000 Australian dollars on a green house.

Financial aspects play an important role with regards to the willingness to build an energy efficient home. In addition, 28 percent of respondents lack confidence in sustainable technology. Such a situation can be improved by providing information about the benefits of new technologies and reliable technologies via mass media. A mere 10 percent of participants have no interest in sustainability, which also reflects the rise of sustainable awareness among the general public. To assist people to save energy and become environmentally friendly, there are a range of ongoing energy rebates, concessions and incentives under the Australian Government's Home Energy Saver Scheme (HESS), such as rebates for installing an efficient water heater and support for installing a solar photovoltaic (PV) system.

4.2 Macro-scale

To some degree, the mode of transportation reflects sustainable awareness among the general public. Figure 7 shows that 45 percent of respondents currently choose to use public transport. Most participants using public transport are full time students and they prefer to live close to a bus or tram stop. 41 percent of participants currently use a private car for travel with the majority using it for their working trip. Only 14 percent of trips taken are done by walking. No respondent chose to use a bike or taxi as their daily commuting tool.

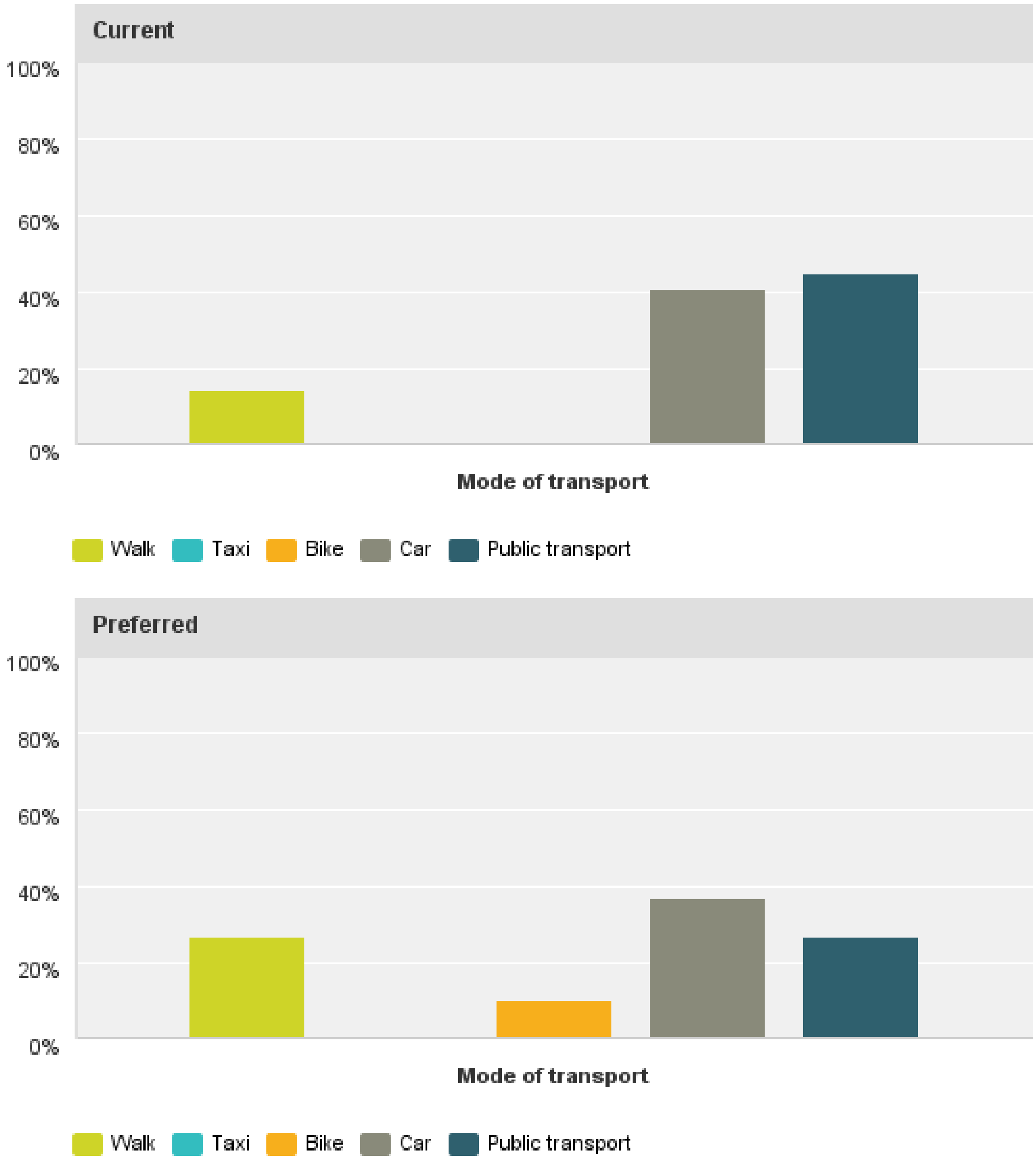


Figure 7 Current and Preferred Mode of Transport

With regards to the preferred mode of transportation, the car has been ranked as the most popular travel mode. 36 percent of respondents prefer to travel by car as compared to 26 percent by public transport. A reason for this may be that the suburban area of Adelaide lacks public transport facilities. It is evident that more cars driving on the road means more carbon emissions. However, more than one third of the participants (36 percent) prefer non-motorised transport tools, with 26 percent and 10 percent for walking and cycling respectively. An increasing number of people living in Adelaide ride bikes to workplaces and places of education.

Location is an important factor in making a home purchase. 78 percent of participants would like to buy their home within 500 metres of a bus stop, followed by recreation areas and train stations. A supermarket is another place that people would like to reach within walking distance. However, 31 percent of the respondents would choose their home to school within a distance of 3km, while almost half of households (45 percent) would like to live further than 3km from their workplace (see Figure 8). This demonstrates the habit of using a private car for daily activities. Mixed use development within Adelaide would bring a multitude of advantages to the city. It brings people together, integrates different land uses and activities and makes people more readily accessible in one location. More efficient use of land could also reduce car dependency thereby improving the general environment.

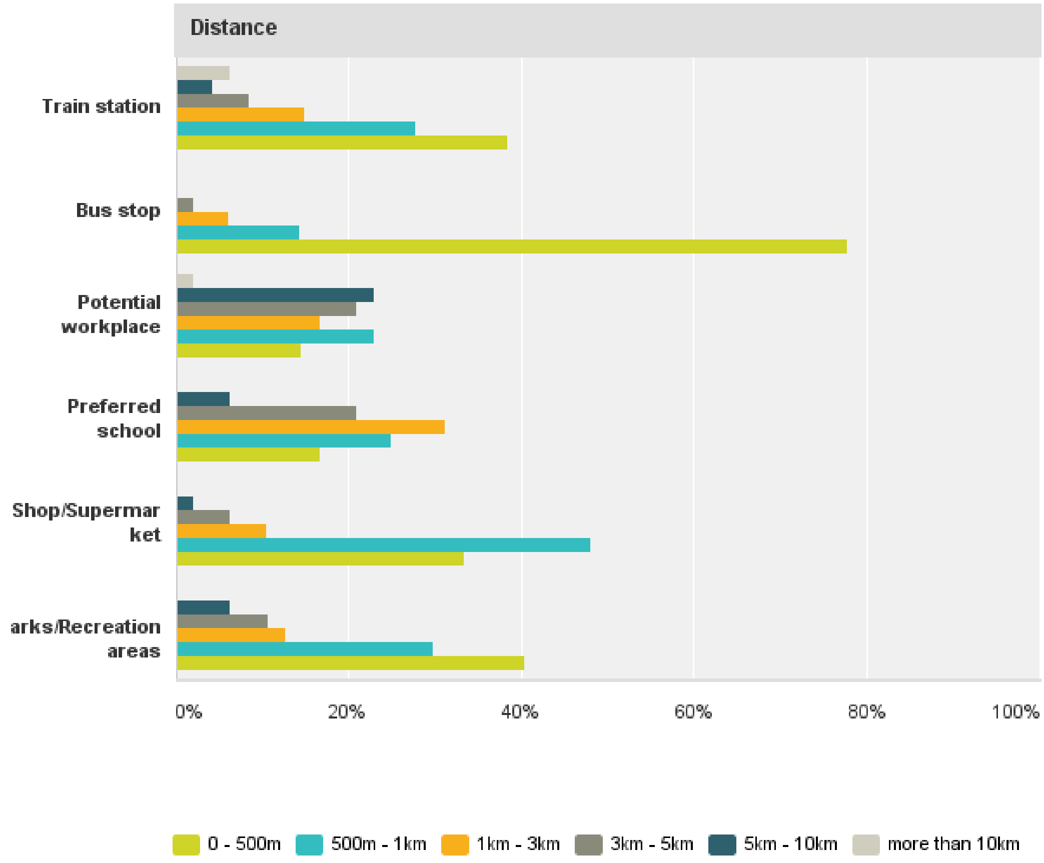


Figure 8 Distance to Key Locations

Due to the nature of the spreading city of Adelaide, it is difficult for public transport to cover all the residential areas. However, there has been a 21 percent increase in bus patronage since 2002, and the tram extension has brought an increase of 25% in tram users (Adelaide City Council 2013). With more people using public transport, there will be less traffic congestion. Another factor that should encourage more public transport use to target cheaper fares and higher frequency as some other Australian capital cities such as Sydney and Melbourne.

Nearly two third of respondents (65 percent) suggest that the government should put more attention into housing affordability, followed by energy use, quality of housing and quantity of housing (see Figure 9). Due to rises in housing prices, more people prefer to rent. As most affordable housing is located in fringe areas with limited public transportation, people have to rely on private cars. This not only increases the use of fuel but also the amount of greenhouse gas emissions. It is suggested that building high rise apartments around public transport and service could be a better solution.

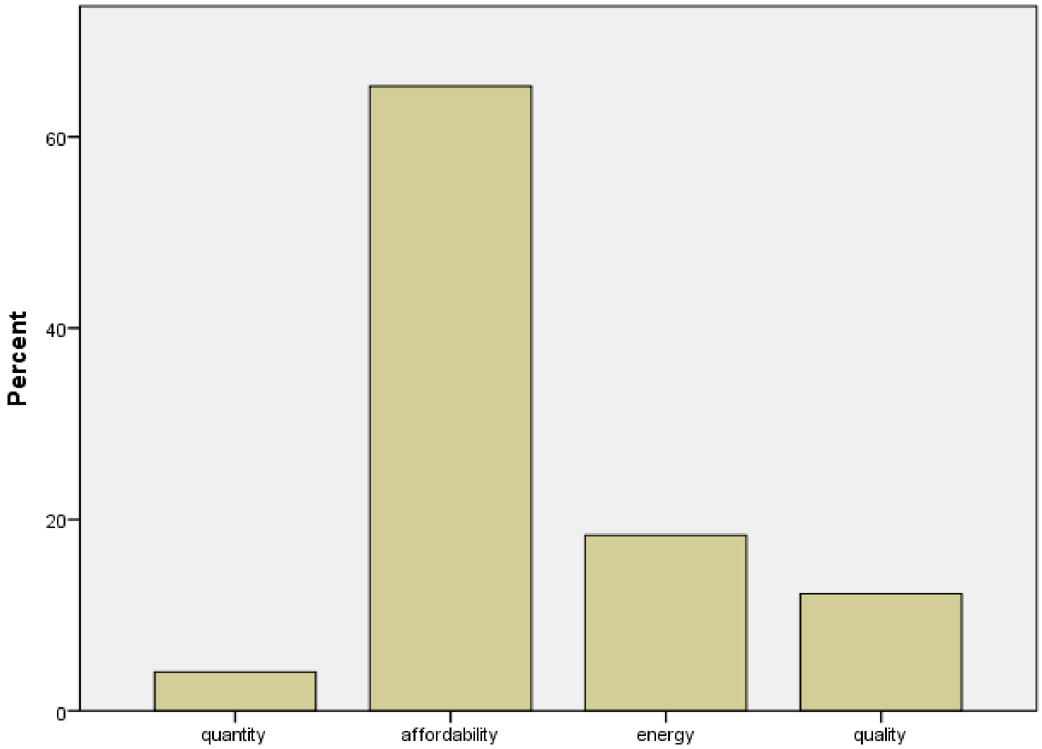


Figure 9 Government's Predominant Policy on the Housing Market

4.3 Socio-demographic and house choice

Figure 10 shows walking, cycling and public transport are more energy efficient compared to driving a car. Women respondents preferred to walk more than men. However, there are fewer women willing to use public transport and no women respondents like to ride a bike.

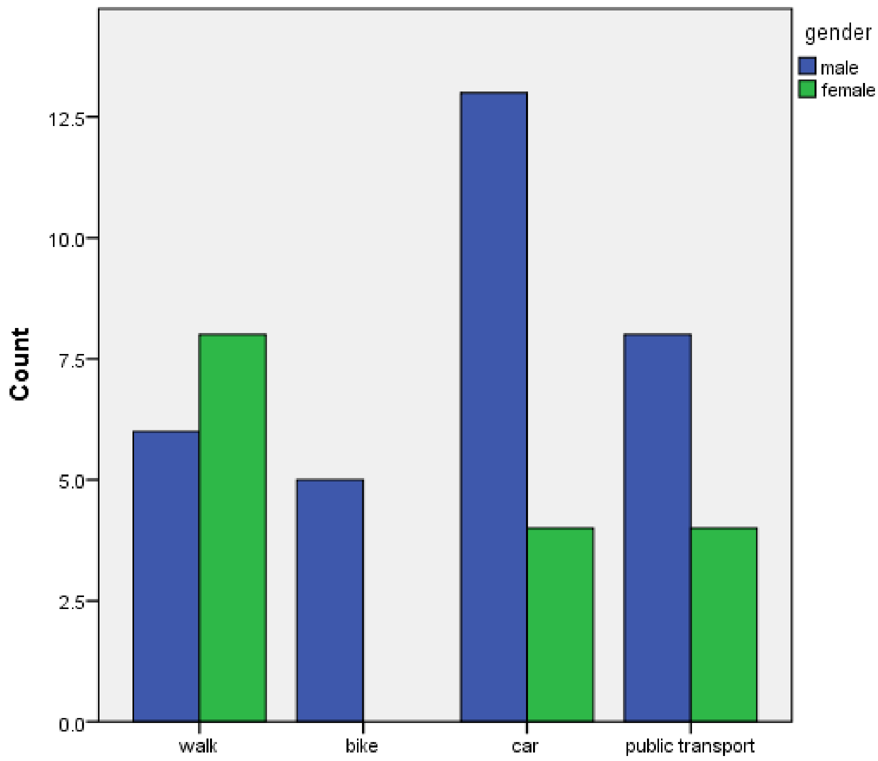


Figure 10 Gender vs. Mode of Transport

Most of the respondents are willing to upgrade their dwellings to save electricity costs. Some of them would spend more than $20,000 dollars to save energy (see Figure 11). The results also show that more men than women ignore energy saving actions. Hence, electricity saving should be promoted more especially to men.

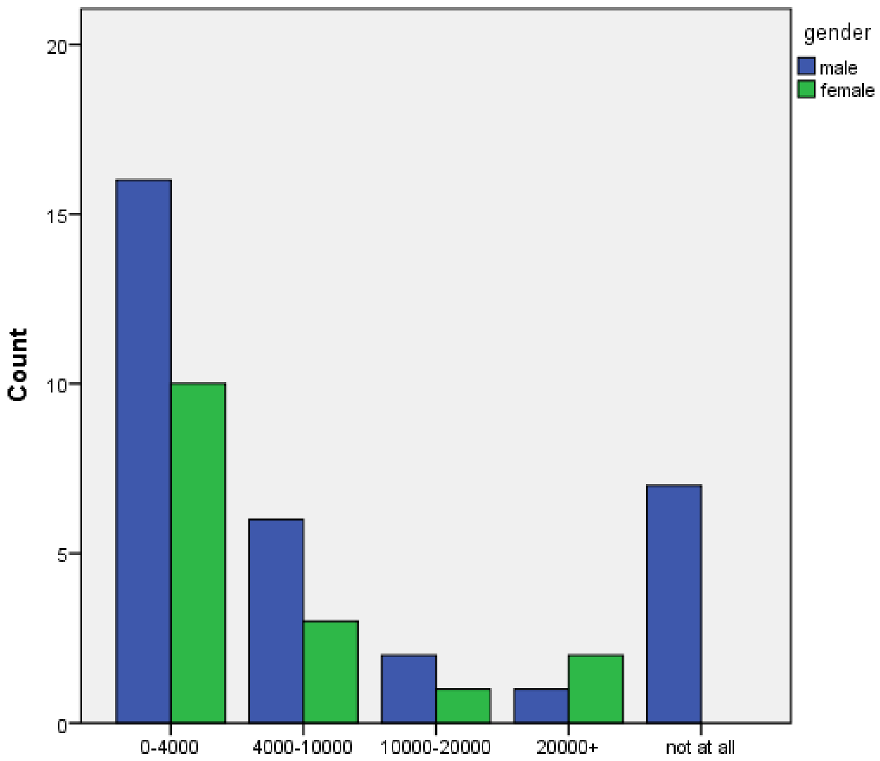


Figure 11 Gender vs. Amount People Invest

Apart from income, different groups have different views on home ownership. Figure 12 displays that most of the full time working group own a property as they have family and therefore a lower possibility of moving. More than 70000 university students in Adelaide rent houses, especially overseas students. This group of young people live with a vibrant lifestyle. Ready access to their university, shopping centres and bus stops are extremely important. Thus, the city centre provides the best location for many of them.

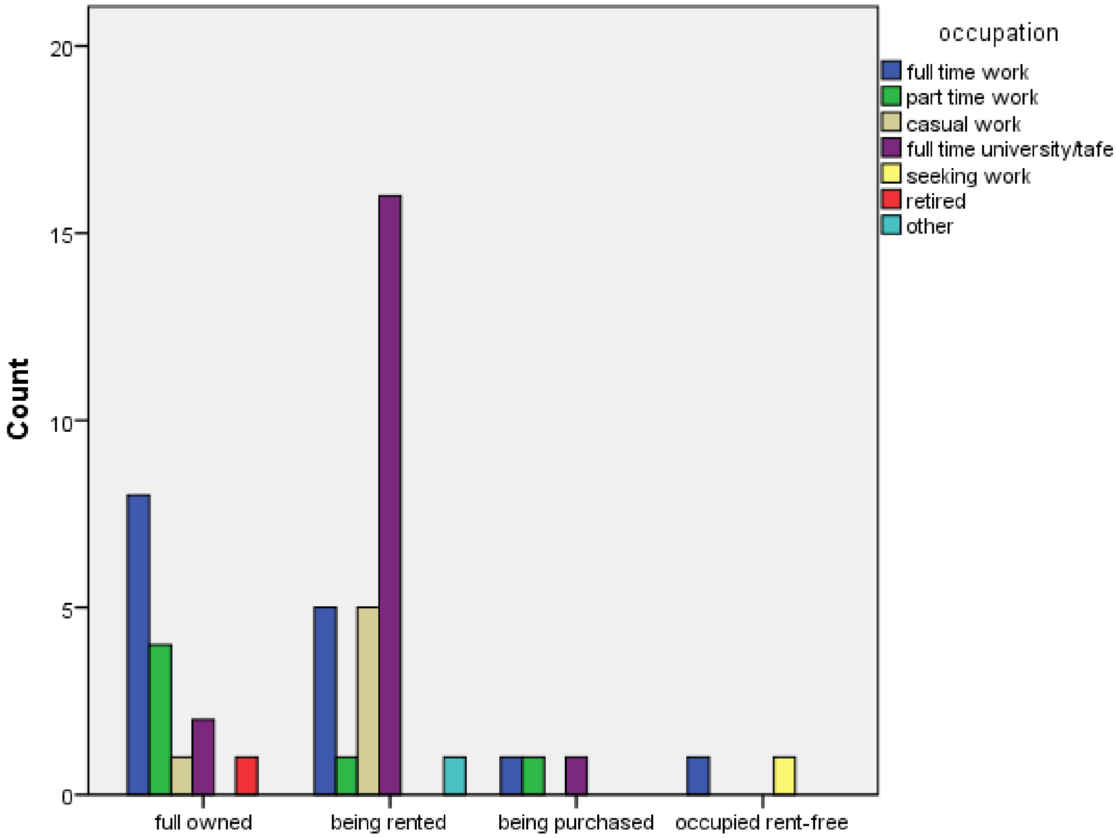


Figure 12 Occupation vs. Ownership

Figure 13 shows that majority of participants who chose public transport are full time students. This is because students prefer to live close to their university and most universities have multiple bus routes that service them making more locations accessible by public transport. Furthermore, the majority who pick walking as the means of transportation are students which also reflect their needs to stay close to school. These findings indicate that mixed use land use near a university is important. On the other hand, the majority who drive are working and may not have sufficient bus services near their homes. It indicates that public transport in Adelaide suburban areas is under supplied to meet the needs of most residents from home to daily activity destinations, especially work places.

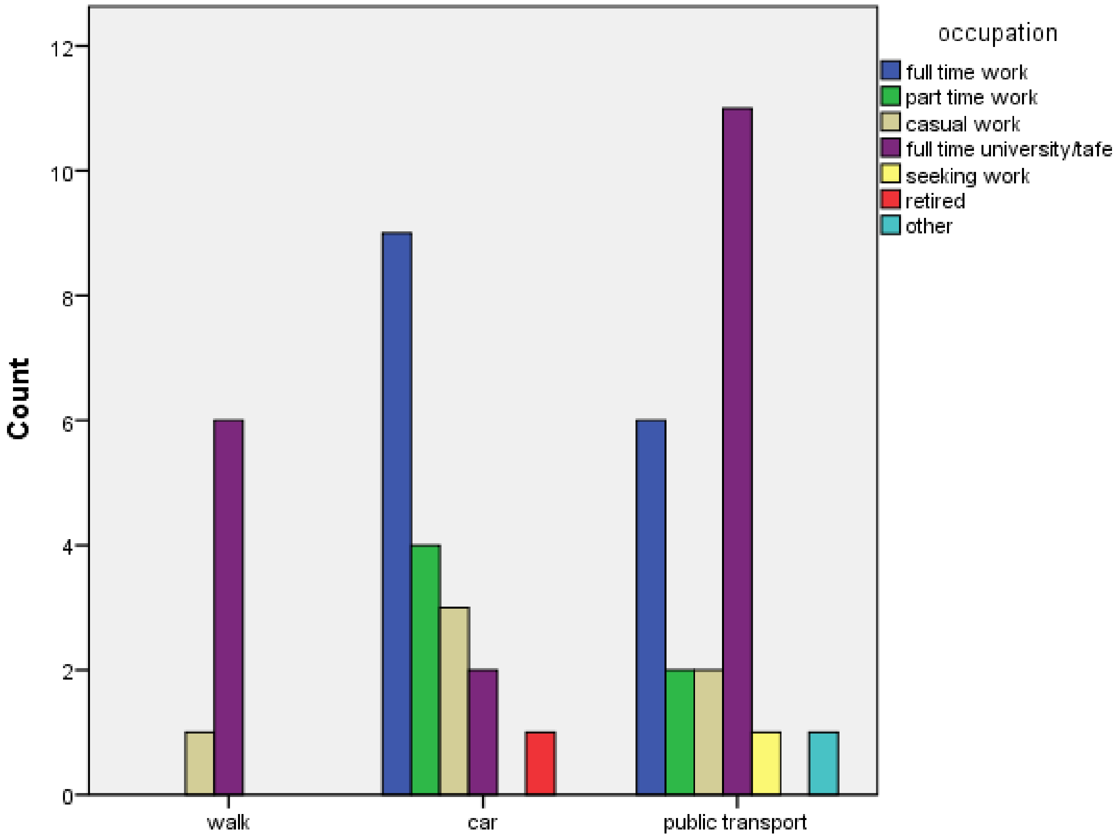


Figure 13 Occupation vs. Current Mode of Transport

Figure 14 shows that most of people who earn more than $799 per week can afford to buy a property, while people with income below $799 per week can only rent. According to the 2011 census, the median monthly mortgage repayment is $1,500, while median weekly rent is $220 (Australian Bureau of Statistics 2013). This indicates that people with more than $800 income would be able to pay for the mortgage without significantly compromising their quality of life. In contrast, if their income is less than $800, rent is a better choice (Note: median weekly household income is $1,044, Australian Bureau of Statistics (2013)).

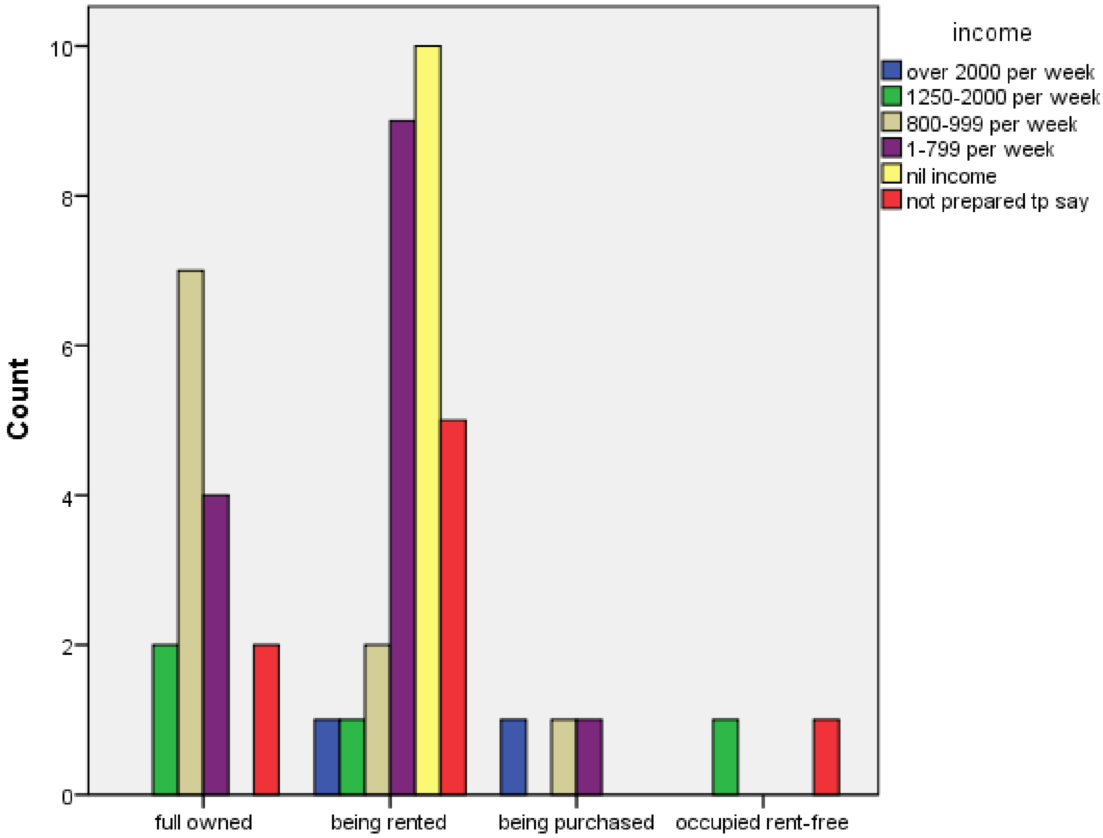


Figure 14 Income vs. Ownership

It is understandable that people with lower incomes consider more about housing affordability (Figure 15). However, all the participants with income over $2,000 per week share the same concern about affordability rather than energy, quantity or quality of housing.

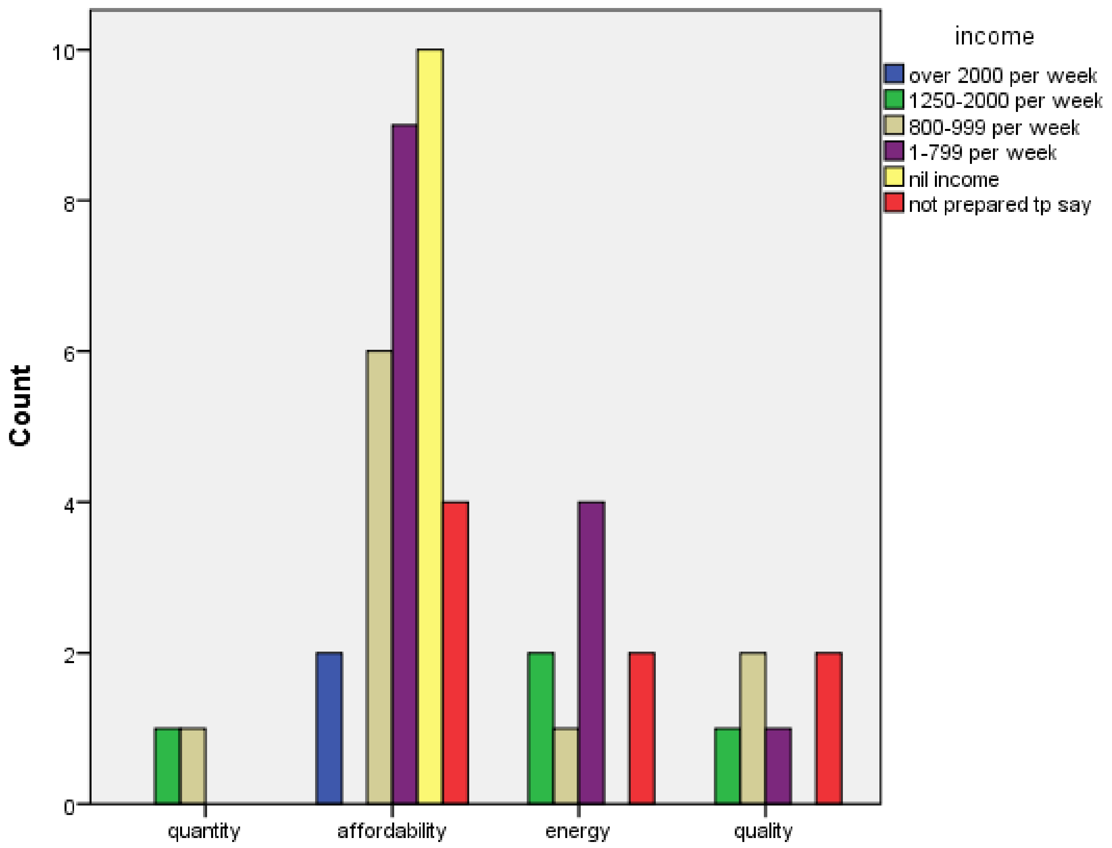


Figure 15 Income vs. Government's Policy on Housing

In regards to the popularity of energy efficient homes, the majority of the respondents were concerned about the costs. They expected that the government should provide more incentives for energy efficient housing. Some of them advised that more information about energy saving should be exposed and promoted to the public.

In terms of how to improve housing affordability in Adelaide, many of them suggested that higher density construction could be an effective way to increase housing affordability. Furthermore, financial incentives should be provided by the government such as the first home buyer grant. Using cheaper materials without compromising their bottom line requirements is another major suggestion from the participants.

5. Conclusion

The construction industry has made substantial contributions to Australia's economy. In view of the differences between high rise apartments and detached houses in the level of sustainability, using wooden materials for low-rise dwellings would minimise carbon emission. Furthermore, a wide range of recycled materials can be used to reduce embodied energy. Regarding operational use, systems within middle to high-rise apartments are much more complex than detached or semi-detached houses. They require more innovative technologies to reduce energy use. Meanwhile, an energy efficient house is a concept which should be promoted.

Medium to high density residential development around transit nodes creates more compact urban form to create easy access to transit and significantly reduce transportation energy use, but building design and operational energy need to target lower energy consumption. Thus, building designs and promotion should be focus on building with an efficient embodied energy design and operational energy conservation together with promoting high density housing.

The majority type of dwelling in Adelaide is a detached house. With an increase in population, and rises in demand for housing and housing affordability, sustainable residential development and urban form are required. Hence, the following recommendations are proposed:

1. More medium to high density residential developments should be built with materials that support both house affordability and low embodied energy.
2. Mixed use projects must be designed from the inception stage, based on the benefits of lower household operational energy consumption.
3. The location of affordable houses should come with easy access to public transportation and services to meet sustainable requirements.
4. More information related to the benefits of sustainable housing should be provided. Support and rebates on innovative technologies are required to attract more residents to adopt them.

For future research, the focus can be on pre-assessment of low embodied energy materials and the building life-cycle. It is important to attain quantitative assessment for sustainable and affordable building in urban infill development (Pullen et al. 2010). Energy consumption and subsequent greenhouse gas emissions are important concerns in sustainable development. Buildings demand energy across their life-cycle from their construction through to demolition. Energy throughout a building’s life cycle can be reduced significantly by the use of passive and active technologies for lowering operating energy, but it has been found that low energy buildings outperform zero operating energy buildings in the life-cycle context (Ramesh, Prakash & Shukla 2010). Therefore it is important to consider and evaluate the life-cycle energy consumption at an early design decision making stage to achieve low embodied energy and minimal environmental impact (Basbagill et al. 2013). Factors that need to be considered in lifecycle framework include house type, materials and technical systems, as suggested in more detail by Schlueter and Thesseling (2009). The authors also recommended a Building Information Model (BIM)-based decision making model as an advanced tool for early stage life-cycle energy assessment, which can quickly iterate different building designs and provide a number of design alternatives.

List of references

Adelaide City Council (2013), Quality public transport, http://smartmoveadelaide.com.au/facts-outcomes/quality-public-transport viewed on 28 October 2013

Australian Bureau of Statistics (2013), 2011 Census QuickStats, Census, http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/4 viewed on 15 October 2013

Australian Government (2008) Making Housing Affordable Again, Department of Families, Housing, Community Services and Indigenous Affairs, http://www.facsia.gov.au/Internet/ facsinternet.nsf/News/housing_affordable.htm. viewed 15 June 2013

Australian Hardwood Network (2013), Environmental Guide, Environment, http://www.hardwood.timber.net.au/environment/embodied.htm. viewed 10 May 2013

Basbagill, J, Flager, F, Lepech, M & Fischer, M 2013, 'Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts', Building and Environment, vol. 60, pp. 81-92.

Beer, A., Kearins, B. and Pieters, H. (2007) ‘Housing Affordability and Planning in Australia: The Challenge of Policy Under Neo-liberalism’, Housing Studies, 22 (1),11-24

Benjamin, J. D., & Sirmans, G. (1997). Mass Transportation, Apartment Rent and Property Values. J. OF REAL ESTATE RESEARCH, 12(1).

Bojic, M., Lee, M., & Yik, F. (2001). Flow and temperatures outside a high-rise residential building due to heat rejection by its air-conditioners. Energy and Buildings, 33(7), 737-751.

Bond, S. (2011). Barriers and drivers to green buildings in Australia and New Zealand. Journal of Property Investment & Finance, 29(4/5), 494-509.

Bourdeau, L. (1999). Sustainable development and the future of construction: a comparison of visions from various countries. Building Research & Information, 27(6), 354-366.

Bryant, L., & Eves, C. (2012). Home sustainability policy and mandatory disclosure: A survey of buyer and seller participation and awareness in Qld. Property Management, 30(1), 29-51.

Buxton, M. (2000) Energy, transport and urban form in Australia, in: K. Williams, E. Burton & M. Jenks (Eds) Achieving Sustainable Urban Form (London: E. & F.N. Spon).

Chen, T. Y., Burnett, J., & Chau, C. K. (2001). Analysis of embodied energy use in the residential building of Hong Kong. Energy, 26(4), 323-340.

Chileshe, N., Khatib, J. M., & Farah, M. (2012). The Perceptions of Tenants in the refurbishment of Tower Blocks. Facilities, 31(3/4), 2-2.

Chow, T. T., & Lin, Z. (1999). Prediction of on-coil temperature of condensers installed at tall building re-entrant. Applied Thermal Engineering, 19(2), 117-132.

City of Salisbury (2009) Brahma Green: Driving Affordable Housing in the City of Salisbury, Project Report, http://cweb.salisbury.sa.gov.au/manifest/servlet/binaries?img=8678&stypen= html viewed 12 June 2013

Department for Families and Communities (n.d). What is Affordable Housing? Adelaide, http://www.dfc.sa.gov.au/pub/tabid/171/itemid/312/What-is-affordable-housing.aspx viewed 10 June 2013

Disney, J. (2007) ‘Affordable Housing in Australia: Some Key Problems and Priorities for Action’, Paper presented at the National Forum on Affordable Housing, 19 Apr 2007, AHURI, Melbourne

Fawcett, R., Allison, K., & Corner, D. (2005). Using Modern Methods of Construction to Build Homes More Quickly and Efficiently. National Audit Office, London.

Forsyth, A. (2003) Measuring Density: Working Definitions for Residential Density and Building Intensity, Design Centre for American Urban Landscapes, Design Brief Number 8, Jul 2003, University of Minnesota, available online http://www.housinginitiative.org/pdfs/from_MDC_Website/db9.pdf

Gerilla, G. P., Teknomo, K., & Hokao, K. (2007). An environmental assessment of wood and steel reinforced concrete housing construction. Building and environment, 42(7), 2778-2784.

Goodchild, B. (1994). Housing design, urban form and sustainable development: reflections on the future residential landscape. Town Planning Review, 65(2), 143.

Government of South Australia 2011, Urban Core Zone, South Australia Planning Library, Adelaide.

Government of South Australia 2013, South Australian Government energy efficiency initiatives, viewed on 10th September 2013, <http://www.sa.gov.au/subject/Water%2C+energy+and+environment/Energy/South+Australian+government+energy+efficiency+initiatives#T60>

Gurran, N., Milligan, V. and Baker, D. (2008) New Directions in Planning for Affordable Housing: Australian and International Evidence and Implications, AHURI Final Report No. 120, Sydney Research Centre

Hampson, K. D., & Brandon, P. (2004). Construction 2020-A Vision For Australia's Property And Construction Industry. CRC Construction Innovation.

Harle, K. (2008). CSIRO Submission 08/281 Garnaut Review–Issues Paper 5–Transport, Planning and the Built Environment.

Li, R.Y.M. (2011) Building Our Sustainable Cities, Common Ground Publishing, Illinois, US

Li, R.Y.M. (2014) Law, Economics and Finance in Housing of the Real Estate Market --A Perspective of Hong Kong and Singapore, Germany, Springer

Low, N., Gleeson, B., Green, R., Radovic, D. (2005) *The Green City: Sustainable Homes*, Sustainable Suburbs. UNSW Press, Sydney, Australia

Mees, P. (2000) A Very Public Solution: Transport in the Dispersed City (Melbourne: Melbourne University Press).

Meng, L. (2013) 'Investigating travel choice in a suburban rail corridor: an Adelaide case study', Transport Systems, School of Natural and Built Environments, Division of Information Technology, Engineering and the Environment, University of South Australia, Adelaide.

Meng, L., Taylor, M.A.P., Holyoak, N. (2012) 'Discrete choice modelling for travel mode and residential location choices in an Adelaide rail corridor', The 17th International Conference of Hong Kong Society for Transportation Studies, 17, Hong Kong.

Ministry for the Environment, New Zealand's Greenhouse Gas Inventory 1990-2007: An Overview, April 2009, New Zealand.

Ministry of Economic Development (MED) (2006), derived from "Direct emissions and indirect electricity emissions from New Zealand Energy Greenhouse Gas Emissions 1990-2005".

National Summit on Housing Affordability (2006) Achieving a National Affordable Housing Agreement: Background Paper 2: Key Terminology and Indicators, National Summit on Housing Affordability, http://www.housingsummit.org.au/media/BP2c.pdf viewed 10 June 2013

News (2014), Melbourne, Adelaide, Sydney and Perth named in top ten of EIU's Global Liveability Index, Viewed 4th Sep. 2014, http://www.news.com.au/

Niu, J. (2004). Some significant environmental issues in high-rise residential building design in urban areas. Energy and buildings, 36(12), 1259-1263.

Ortiz, O., Castells, F., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23(1), 28-39.

Perkins, A., Hamnett, S., Pullen, S., Zito, R., & Trebilcock, D. (2009). Transport, housing and urban form: the life cycle energy consumption and emissions of city centre apartments compared with suburban dwellings. Urban Policy and Research, 27(4), 377-396.

Powerhouse Museum, no date. Brick Veneer House Construction,
prestige without the price, viewed 4th Sep. 2014.
http://www.powerhousemuseum.com/australia_innovates/?behaviour=view_article&Section_id=1040&article_id=10102

Pullen, S., Arman, M., Zillante, G., Zuo, J., Chileshe, N., & Wilson, L. (2010). Developing an assessment framework for affordable and sustainable housing. Australasian Journal of Construction Economics and Building, 10(1/2), 48-64.

Pullen, S., Holloway, D., Randolph, B. and Troy, P. (2006) 'Energy Profiles of Selected Residential Developments in Sydney with Special Reference to Embodied Energy', Proceedings of the Australian & New Zealand Architectural Science Association (ANZAScA) 40th Annual Conference. 22-25 Nov.

Ramesh, T, Prakash, R & Shukla, KK 2010, 'Life cycle energy analysis of buildings: An overview', Energy and Buildings, vol. 42, no. 10, pp. 1592-1600.

Randolph, B., Kam, M. and Graham, P. (2008) Who Can Afford Sustainable Housing in Nelson, A (Ed.) Steering Sustainability in an Urbanising World, Aldershot, United Kingdom

Rickwood, P., Glazebrook, G. & Searle, G. (2008) Urban structure and energy—a review, Urban Policy and Research, 26(1), pp. 57–81.

Rickwood, P., Glazebrook, G. and Searle, G. (2008) 'Urban structure and energy—a review', Urban Policy and Research, 26 (1), 57–81

SA Govt (2009) *Planning the Adelaide We All Want. Progressing the 30 Year Plan for Greater Adelaide.* Department of Planning and Local Government. Government of South Australia. Draft for consultation. Jul

Sachs, J. D., & Warner, A. M. (1995). Natural resource abundance and economic growth (No. w5398). National Bureau of Economic Research.

Schlueter, A & Thesseling, F 2009, 'Building information model based energy/exergy performance assessment in early design stages', Automation in Construction, vol. 18, no. 2, 3//, pp. 153-163.

Sustainable living in Sweden (2013) Living for the future, viewed on 12th October 2013, < http://sweden.se/nature/sustainable-living>

Spence, R., & Mulligan, H. (1995). Sustainable development and the construction industry. Habitat international, 19(3), 279-292.

Tam, C. M., Deng, Z. M., & Zeng, S. X. (2002). Evaluation of construction methods and performance for high rise public housing construction in Hong Kong. Building and environment, 37(10), 983-991.

Urban Development Institute of Australia (2013). The 2013 UDIA State of Land Report. http://www.udia.com.au/_literature_161041/2013_State_of_the_Land_Report

Vollenbroek, F. A. (2002). Sustainable development and the challenge of innovation. Journal of Cleaner Production, 10(3), 215-223.

Wang, X., Chen, D., & Ren, Z. (2010). Assessment of climate change impact on residential building heating and cooling energy requirement in Australia.Building and Environment, 45(7), 1663-1682.

Wilson, A. and Laskey, N. (2003), “Internet-based marketing research: a serious alternative to traditional research methods?”, Marketing Intelligence & Planning, Vol. 21 No. 2, pp. 79-84.

Yates, J., Kendig, H., Phillips, B., Milligan, V. and Tanton, R. (2008) Sustaining fair shares: the Australian housing system and intergenerational sustainability, Final Report, AHURI Sydney Research Centre

Yates, J., Milligan, V., Berry, M., Burke, T., Gabriel, M., Phibbs, P., Pinnegar, S. and Randolph, B. (2007) Housing Affordability: A 21st Century Problem. National Research Venture 3: Housing Affordability for Lower Income Australians, Final Report, AHURI Sydney Research Centre

Yoshino, H., Yoshino, Y., Zhang, Q., Mochida, A., Li, N., Li, Z., & Miyasaka, H. (2006). Indoor thermal environment and energy saving for urban residential buildings in China. Energy and buildings, 38(11), 1308-1319.