Exploring housing resource consumption associations with sustainable housing design and occupant attitudes:

A south-east Queensland study

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ETHICS APPROVAL

The University of Sydney Human Research Ethics Committee approved the research (protocol number: 13310) on 14 January 2011.

DECLARATION

This Thesis is my original work, and has not been submitted, in whole or in part, for a degree at this or any other university. Nor does it contain, to the best of my knowledge and belief, any material published or written by another person, except as acknowledged in the text.
ABSTRACT

Sustainable development is promoted as a means to address climate change impacts and sustainable design is believed to have a strong role in determining the operational performance of housing. However, in relation to residential housing, these assertions have been largely untested by academic research and occupant impacts are not often considered alongside design influences. Consequentially, the present study aimed to investigate whether sustainably designed housing actually has less impact on the environment and the extent to which occupant attitudes play a role in any reduction, for technical and non-technical factors.

The study was able to compare 75 houses drawn from a conventional housing estate and a sustainability-focused residential community. The latter community imposed strict environmental building codes. The conventional housing community, which was designed using contemporary methods, did not preference or require the application of sustainable design principles and was used as the “control group”. The houses within the second estate (the “study group”) employed a high level of sustainable design principles, including solar energy, intentional building orientation, natural ventilation, no air conditioning, recycled materials, reduced indoor environment toxicity and solar passive design.

Utility consumption data and surveys were used to gather the data in early 2011. The “study group” houses were found to use 75 per cent less net energy (5.7kWh per day) compared with the “control group” of conventional homes. Interestingly, the water consumption for both types of housing was found to be very similar, although the study group had implemented its own internal rainwater capture and recycling system, which uses no water from the central town water system.
It was hypothesised that among the variables studied, multiple regression analysis showed that the number of occupants and then a house’s sustainable design, influenced energy consumption the most, suggesting that sustainable design of a house is a key factor in reducing household utility use. In contrast, environmental attitudes and the size of the house, explained less than one per cent of the variance in energy use, further highlighting the value of sustainable design attributes in terms of operational energy reduction. The results also suggested that the sustainable design of a house is twice as likely to reduce its energy consumption compared with the influence of pro-environmental attitudes.

The survey results revealed that higher levels of attitudes favourable to environmental conservation correlated with lower energy use, but attitudes were not found to offer any statistically significant independent prediction of energy use when analysed with other predictor variables present. Similarly, the results were not able to demonstrate that environment-based attitudes and behaviours contributed significantly to lower energy use, when other demographic housing design factors had already been taken into account.

In conclusion, the study suggests that stronger prioritisation of the sustainable design attributes in housing will significantly reduce anthropogenic environmental impact. Similarly, it appears possible to undertake such actions without impacting occupant well-being.
ACKNOWLEDGEMENTS AND CONTRIBUTIONS

I would like to thank my supervisors, Professor Richard Hyde (University of Sydney) and Dr David Wadley (University of Queensland) for having the foresight to plan this research and obtain grants to support its completion as well as for their support and supervision throughout the project. The assistance of Dr Heather Green (Griffith University) with statistical analyses and editing was highly valued. I worked well and closely with the University of Sydney PhD student Anir Upadhyay on the project. The focus of Anir Upadhyay’s study was on the Quality of Life neighbourhood satisfaction survey results, social level and “Quality of Life” implications and was designed to complement the results of this present “utility impact” focused study. Anir Upadhyay provided valued support during the research period, specifically during the design and data collection phases. I would also like to thank the local research assistants, Collette Morris and Sam Pforr, who put in extra effort to ensure the study was of high quality and completed sensitively.

The project was only possible thanks to all the participants who kindly gave their time to complete the surveys and feedback.

I would like to dedicate this work to two amazing people; Chris J. Walton, who provided mentorship and gifted me with a wonderful opportunity, and Bond University Associate Professor Andrew (Wilf) Wilford who was an inspiration to me through his teachings.

The overall research project was led by the University of Sydney, primarily funded by the Australian Research Council and study partners including Landmatters Pty Ltd, Queensland Department of Natural Resources and Mines (DERM), EcoVision and Gold Coast City Council (Gold Coast Water/Allconnex).
The referencing and formatting of the document have been prepared to be consistent with the Publication Manual of the American Psychological Association (APA) 5th edition.
PREFACE

This study was part of a broader research project undertaken to develop a Quality of Life model in relation to sustainable housing. The aim of the wider project is to provide evidence that would inform policy development and test claims about the performance of sustainable housing to support a new model. The broader research project is titled “Quality of Life in environmentally intentional and un-intentional housing: A comparative study from South East Queensland, Australia”. The research specifically required the measurement of housing resource consumption, occupant attitudes and neighbourhood satisfaction, from a population that claimed to be sustainable, and a separate but comparable control group.

To ensure coverage, the research project was divided into two parts. The housing performance study is described by this thesis using housing resource consumption results, namely energy and water data. It also recorded and utilised demographic data, such as house size, the number of occupants and age of the homes, as shared by both studies. The second study leveraged the results of the first study and additionally focused on findings regarding householders' satisfaction with their residential neighbourhood environment, to develop the environmental Quality of Life (QoLe) model. The latter study was led by University of Sydney Doctor of Philosophy (PhD) candidate, Anir Upadhyay, who prepared environmental attitude questionnaires that were used as a proxy for behaviour. The raw environmental attitude data were also shared by both studies to test different hypotheses.

A graphical overview of the relationships analysed in the present project and the PhD study is shown in: APPENDIX A – Research focus and relationships.
An Australian Research Council (ARC) grant (LP0774952) and industry assistance was obtained in 2007 and provided the funding with partners for the project. In 2010, I was invited to become part of the research team, which had already started preparing some of the project background. I began the research part time and completed the data analysis in 2011-2012.

From a personal, professional and research perspective, I was interested in evaluating the intentions, ideas and outcomes of the estates targeted by the present study. I had previously worked on the sustainably focused estate’s development for 12 months in 2005 and have most recently lived in the estate for two years. To ensure objectivity, I worked with other students and ensured that the study used standard quantitative measures. For example, the energy and water data were available from the monitoring systems and utility bills and the environmental attitude data were measured using the Environmental Attitudes Inventory based questionnaires which had been previously tested and validated. I managed the water and energy data preparation, design and collection. Anir Upadhyay provided the Environmental Attitudes Inventory question selections and both sets of data were shared to enable each of us to focus on our particular questions of interest.


# GLOSSARY

<table>
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<th>Description</th>
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<tbody>
<tr>
<td>AUD$</td>
<td>Australian Dollar</td>
</tr>
<tr>
<td>ALC</td>
<td>Architecture and Landscape Codes</td>
</tr>
<tr>
<td>BCA</td>
<td>Building Code of Australia</td>
</tr>
<tr>
<td>BERS</td>
<td>Building Energy Rating Scheme tool</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
</tr>
<tr>
<td>CO$_2$e</td>
<td>Carbon Dioxide equivalent emissions</td>
</tr>
<tr>
<td>DTS</td>
<td>Deemed-to-Satisfy</td>
</tr>
<tr>
<td>ESD</td>
<td>Ecologically Sustainable Design</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gases</td>
</tr>
<tr>
<td>GHA</td>
<td>Global Hectares</td>
</tr>
<tr>
<td>GFA</td>
<td>Gross Floor Area</td>
</tr>
<tr>
<td>House</td>
<td>Physical infrastructure of a single residential dwelling</td>
</tr>
<tr>
<td>Housing</td>
<td>Multiple houses</td>
</tr>
<tr>
<td>Home</td>
<td>House, including the occupants</td>
</tr>
<tr>
<td>Householders</td>
<td>House occupants</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, ventilation and air conditioning</td>
</tr>
<tr>
<td>EAI</td>
<td>Environmental Attitudes Inventory</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change (IPCC)</td>
</tr>
<tr>
<td>IWEC</td>
<td>International Weather for Energy Calculations</td>
</tr>
<tr>
<td>LED</td>
<td>Light emitting diode</td>
</tr>
<tr>
<td>LEED</td>
<td>Leadership in Energy and Environmental Design</td>
</tr>
<tr>
<td>NatHERS</td>
<td>Nationwide House Energy Rating Scheme</td>
</tr>
<tr>
<td>NABERS</td>
<td>National Building Energy Rating System</td>
</tr>
<tr>
<td>NZEB</td>
<td>Net zero energy building</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>SHGC</td>
<td>Solar heat gain coefficient</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<td>USA</td>
<td>United States of America</td>
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INTRODUCTION

"Economics and a reliance on science and technology to solve our problems has led to an unsustainable situation where continued growth in consumption is required for governments and business to be considered successful. This is a form of insanity. Economics is at the heart of our destructive ways and our faith in it has blinded us". Dr David Suzuki, Canadian scientist. (Suzuki, 2002, p. 1)

Background

Western countries are investing significant time, effort and capital to address climate change impacts by constructing more sustainable buildings to reduce environmental impacts (Glicksman, Norford, & Greden, 2001; Kibert, 2007). Similarly, research is underway to better understand the impact of sustainable design and behaviour on resource use, which is critical if policies are effectively to address the global impacts of the residential housing sector. However, the effects of such policies and programs are not well understood (A. C. Nelson, Pendall, Dawkins, & Knaap, 2002). As a result, it would appear valuable to focus additional research on sectors that have not been adequately investigated for opportunities to make significant change. For example, knowledge about the residential housing sector's ability to reduce environmental impacts is relatively unknown compared to the non-residential construction sector (Lorenz, Truck, & Lutzkendorf, 2007; Lutzkendorf & Lorenz, 2005). This study aimed to highlight such relationships and test opportunities to live more sustainably within the residential housing sector.

Australians were the second highest per capita greenhouse gas (GHG) emitters in the world in 2000 at 27 tonnes of CO$_2$e per annum (Karoly & Cosier, 2009). Another measure of human consumption impact, the ecological footprint, estimates the global share of resources used, in global hectares (GHA) per person. In
2008, Australia’s ecological footprint was calculated as 7.8 GHA/person, compared with the global average of 2.7 GHA/person and less than 1.0 GHA/person for the majority of African nations (WWF, 2009). In the state of Queensland, where data for this project were collected, a 2007 State of Environment Report reported that the Queensland ecological footprint was more than three times the world average (Queensland Department of Environment and Resource Management, 2007). One avenue to investigate a major component of these impacts was by focusing on the property and construction industry, where significant environmental impact is evident (United Nations Environment Programme, 2006). Mitigating such impacts can be viewed as a design or technology based opportunity, with technology still not being widely adopted by industry according to the Intergovernmental Panel on Climate Change (IPCC) (Levine et al., 2007, p. 406).

Significance

The study was specifically designed to address the need for stronger evidence regarding operational impacts of the residential housing sector. It aimed to provide a better understanding of the relationships between design and attitudes affecting residential building utility consumption to enable policies to influence consumption with more certainty (Christie, Stoecklein, & Donn, 2009). The building sector contributes up to 40 per cent of greenhouse gas emissions, so it is a logical target for seeking efficiencies, rather than sectors with more fixed constraints and less flexible demand (United Nations Environment Programme, 2006). Without such an understanding it could be more difficult to target the residential built environment and reduce its impact on the environment, which all humans and other life, inextricably depends on.
Research Questions

To seek the appropriate evidence and fill the knowledge gap, the study aimed to answer three related questions, namely:

(a) how do sustainably designed residential buildings compare with conventional homes in the same climate zone in terms of operational resource consumption?

(b) what impact do environmental attitudes have on household utility usage?

and

(c) what is the relationship between sustainably designed residential buildings and an occupant’s environmental attitudes?

In this thesis it is proposed that building design is a critical factor when attempting to reduce utility consumption, and further that occupant behaviours play a substantial role in contributing to such consumption.

In an attempt to answer such questions, key variables that could be measured where identified and targeted. They included household utility (energy and water) consumption as a dependent variable, and environmental attitudes and housing sustainable design attributes, as the independent variables. Demographic data were also captured to aid analysis and comparison. It was felt important to include the attitudes of the occupants because to date, the focus stemming from the advent of environmentalism, had been on the buildings themselves, which are typically easier to measure and target in the absence of behavioural information (Janda, 2011).

Methodology Overview

The study was able to address these issues by targeting specific populations of interest. It used Ecovillage at Currumbin ("Ecovillage") as the "study group" of interest. The Ecovillage is an intentional community which uses an array of
sustainable design features, and was compared in early March 2011 with a conventional “control group” estate called “The Observatory” at Reedy Creek in Queensland, Australia. The research design was enhanced by being able to match for climate zone and age of homes across the two groups, given that both were relatively new developments and located in the same region. Environmental attitudes were used as a proxy for behaviour and measured using an abbreviated version of the Environmental Attitudes Inventory completed by one adult occupant of each home. Seventy-five occupants were surveyed and each home had energy and water consumption analysed. A real time utility monitoring system installed in the Ecovillage homes assisted by providing more detailed utility data.

Thesis Structure

The thesis is divided into four chapters. Chapter 1 defines sector-specific terminology, the study framework and study variables, whilst identifying and reviewing previously completed research on related topics. Literature on the combined effect of variables for both sustainably designed and contemporary homes was not evident, so the literature references present studies that target typically only subsets of the variables of interest. This chapter defines the study hypotheses.

Chapter 2 describes the research method in detail, identifying the populations of interest, procedures used and the intended analytical method.

Chapter 3 details the results, per variable, then though correlations and finally a multivariate analysis, to provide answers to the hypotheses. Discussion of the key results is provided in Chapter 4, which is completed with a conclusion.
It has been reported that sustainably designed buildings can outperform conventional homes for some comfort factors and that occupant satisfaction with such housing can be higher than convention housing (Schnieders & Hermelink, 2006). Building a “sustainably designed” house might also assist in reducing consumption through passive measures, but it is additionally hypothesised for the present study that consumption efficiencies can also be enhanced by the behaviour of the occupants within the home. To date, the impacts of sustainable design and occupant variables have not been quantified for detached houses and nor have previous studies measured utility consumption in conjunction with attitudes, from multiple intentionally sustainable and comparable conventional homes. Before detailing the previous related studies, the key definitions are described below.

Why sustainable development?
The impact of human development on the planet is well documented and often described as unsustainable, and as a result sustainable development has been adopted as a solution by many governments to perceivably address the decline in natural systems. However, literature defining the causes is limited. Scientific evidence indicates that average Earth temperatures are rising and that these changes are very likely to be as a result of increasing anthropogenic GHG emissions and not the result of the natural variability of climate (Intergovernmental Panel on Climate Change, 2007). A large majority of the world’s leading climate scientists have warned that these anthropogenic impacts on climate need addressing urgently:

“There is a strong (scientific) consensus around a series of key, inter-related, propositions: that climate change is happening, that climate change has anthropogenic causes, that human-induced climate change poses a serious
threat to humanity, and that the threat is not likely to be met by voluntary
action”. (Goot, 2010, p. 1)

The majority of the scientific community agree that mainstream human
development is currently unsustainable (Goot, 2010; Houghton et al., 2001). A study
by the University of Illinois concluded that “it seems the debate on the authenticity
of global warming and the role played by human activity is largely nonexistent
among those who understand the nuances and scientific basis of long-term climate
processes” (Doran & Zimmerman, 2009, p. 22). As a result, it may be concluded as
the basis of this study that human activity is causing climate changes and that
housing plays a part in this impact.

Concerns about permanent environmental impact by humans have been
documented through all stages of history according to Simmons (1993). However, it
would appear that world wars and specific environmental issues have brought more
attention to the issues in recent decades. In the 1960s literature such as Carson’s
(1962) Silent Spring and The Population Bomb by Ehrlich (1968) highlighted
concerns about toxicity and population growth. Soon afterwards, the United Nations
started taking a more proactive role through several significant events (Milfont &
Duckitt, 2007). These included the 1972 United Nations conference in Stockholm
and The Earth Summit conference in Rio de Janeiro in 1992, from which the global
plan of actions for the 21st century called Agenda 21 was generated. Agenda 21 is
used by over 2000 local governments across 64 different countries to provide a
connection between the goals and local programs to address climate change
(Government of South Australia, 1999).

The 1983 World Commission on Environment produced the frequently
referenced document titled Our Common Future, often referred to as the Brundtland
Report (World Commission on Environment and Development, 1987), which gave rise to the most well known definition of sustainable development as described in the next section.

In regard to more recent international approaches to assess environmental impacts, the IPCC was set up in 1998, in response to growing concern about human-induced global climate change (Bolin, 2007). The IPCC is a scientific and an intergovernmental body, with 195 member countries (IPCC, 2012). It sees its role as to assess the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. The IPCC Fourth Assessment Report highlighted that substantial market barriers stand in the way of making environmentally beneficial improvements in the building sector (Levine et al., 2007). The IPCC has stated:

“While occupant behaviour, culture and consumer choice and use of technologies are also major determinants of energy use in buildings and play a fundamental role in determining CO₂ emissions (high agreement, limited evidence), the potential reduction through non-technological options is rarely assessed and the potential leverage of policies over these is poorly understood”. (Levine et al., 2007, p. 389)

Indeed, if non-technological options can be assessed and targeted by incentive schemes or related policy initiatives, previously unobtainable GHG reductions should be achievable. The commercial sector has typically been more motivated to reduce energy and GHG emissions because it can see and obtain direct benefits from implementing upgrades. Commercial enterprises also benefit from their better economies of scale due to the size of buildings, financial resources and access, and knowledge of facility management. In contrast, the residential sector suffers because individuals do not possess the knowledge, funds or time to plan,
specify and make house improvements. Hence this sector should be a target for much more research, to resolve these gaps and realise the previously untapped savings. Further study into attitudinal impacts on GHG emissions and the economic elasticity for GHG improvement is also recommended to capture this opportunity for improvement, especially in countries where social status is playing a significant role in materialism and consequential environmental destruction.

One model currently used to describe the present issues concerning pressures on natural systems is known as the Pressure State Response (PSR) model (Greening & Gray, 1994; Hyde, 2007). This model attempts to identify the responses that are required to address pressures on natural systems and these target energy consumption, water production and material use which are all affected by the rates and types of housing development. The model was accepted by many agencies in the early 1990s, and is now employed widely. It was derived from “cause and effect” assessment and enabled alignment with the United Nations System of National Accounts (Food and Agriculture Organisation, 2012).

If research based on such models could demonstrate that sustainable design does not cost any more and can maintain or enhance Quality of Life rather than threatening it, it might become the dominant paradigm (Crabtree, 2005). That is, consumers who are unaware or without the knowledge, can be drawn towards the lowest (initial capital) cost items (including houses). This can result in manufacturing processes that cut prices by externalising costs (Heal, 2008). This tendency has a detrimental effect on the environment, and the distances between consumers, raw materials and decision authorities merely enhance this impact (Princen, 1997). This disjunction suggests that costs need to be fully internalised, such as putting a price on a litre of clean air and water, which is what carbon taxes...
attempt to do, for one measure of air toxicity (Boyle & Kiel, 2001). Otherwise, mandatory requirements may need to be put in place to ensure only sustainable products are used and designs are employed (Arnold & Whitford, 2006). In theory, over time sustainable practices should become the lowest cost methods, because population pressures aside, they do not involve additional processes and components (Hawken, Lovins, & Lovins, 2010; McDonough & Braungart, 2002; Sikdar, 2003).

Upfront capital costs, such as implementing technical solutions to improve a home’s ability to reduce its environmental impact, can be seen as a barrier to building more sustainably and reaping a return on investment from operational savings over the long term (McGee & Partridge, 2008). For example, price sensitive consumers or those without access to capital to make investment, will not often invest in design enhancements (such as improved glazing or natural cooling solutions) even though they could provide financial savings in the longer term and possibly other less tangible benefits, such as improved air quality or daylight which has been shown to impact moods (Kuller, Ballal, Laike, Mikellides, & Tonello, 2006). Information about such returns on investment is increasing, however, especially in Australia on the back of solar rebate programs (T. Nelson, Simshauser, & Kelley, 2011).

As little detailed research has been undertaken to compare the post-occupancy impacts of sustainable design attributes on housing, questions still remain regarding how they affect operational resource consumption (Carmona, 2001; Ryghaug & Sorensen, 2009; Woodbury et al., 2009). In this regard, the present study compared sustainably designed buildings, as defined earlier, and those designed only to meet mandatory requirements (in this case, the Building Code of Australia and local government requirements).
Defining Sustainable Development

The term *sustainability* has been frequently misused in recent times to badge products and practices as being good for the environment (Choguill, 2007). It has also been used to legitimise calls for unbridled economic growth (Manderson, 2006). However, “sustainability” in its purest form merely means the ability of one system to sustain another system over time (Bossel, 2003; Manderson, 2006). On this basis, we need to assume that those purporting to claim a level of sustainability are actually referring to sustainable development, sustainable design or sustainable behaviour. Yet such terms appear to have now been overused, blurring and diluting their true meanings (Ha, 2007). The meaning of such terms is also strongly dependent on the context in which they are applied and whether their use is based on an economic, social, or ecological basis (Brown, Hanson, Liverman, & Merideth, 1987; Kay, Regier, Boyle, & Francis, 1999).

If *sustainable development* is defined as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p. 16), then the post industrial revolution emission of GHG cannot be classified as sustainable development. Birkeland (2008) goes so far as to suggest that the goal should be to impact positive development, if humans are additionally to negate our negative impacts on the environment to date. The Commonwealth Government of Australia defines ecologically sustainable development as “using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased” (Ecologically Sustainable Development Steering Committee, 1992, p. 1).
Sustainable Design

Sustainable design is often a sub-set of sustainable development, and is a term that should be used to describe the design of systems that can be sustained indefinitely or, in the context of human development, as the “conception and realisation of environmentally sensitive and responsible expression” as identified in the *Hannover Principles* developed by William McDonough Architects (McDonough, Braungart, & Kerry, 2003, p. 4) and listed in APPENDIX B - The Hannover Principles for Sustainable Design. Such development design is often termed Ecologically Sustainable Design (ESD) (Horne, 2006). The Royal Australian Institute of Architects defines ESD as “the use of design principles and strategies which help reduce the ecological impact of buildings e.g. by reducing the consumption of energy and resources, or by minimising disturbances to existing vegetation” (Fowcett, Palich, & Nervegna, 2006, p. 6).

For the purposes of differentiating the main types of housing, the term *sustainably designed* is defined for this research as house design that is planned to be more socially, environmentally and economically sustainable (Queensland Government, 2010). Note that sustainable buildings are also frequently referred to as Green Buildings in the property market and in this context these two terms can be viewed as identical labels (Lutzkendorf & Lorenz, 2005).

In terms of housing, a building that used only sustainable design would in theory be totally self-sufficient and have no net negative impact on the environment (Rosen, Dincer, & Kanoglu, 2008), whilst delivering an acceptable level of well-being to its occupants (Lee, 2002). Given that such outcomes are difficult to measure and achieve, especially with high expectations and living standards in western and developing countries, a house that is merely aiming for self-sufficiency can probably...
only be labelled as more sustainable, compared to its with industry peers. That is, most Western buildings termed sustainable are merely a bit more sustainable and not truly sustainable in the purist sense of the definition (Jabareen, 2008).

As distinct to Australian housing, many homes in Africa, India and China could potentially meet the theoretical definition of sustainable housing, but some would argue this outcome occurs at the expense of quality of life, democracy or standards of living, despite evidence of stronger family ties in such living environments (Alesina & Giuliano, 2010). To set the scene, a mud brick dome, igloo, cave or North American tee-pee (made out of cow hide and timber) could arguably be seen as the only present forms of sustainable dwellings (Snell, 2004). The literature has also linked such definitions to Quality of Life (Hyde & Rostvik, 2008; Seyfang, 2010) and evolved to capture alternative measures and perspectives, such as carbon neutral housing or zero-carbon housing (P. W. Newton & Tucker, 2010).

For this project, the study group housing contained many more sustainable design features and typically achieved a higher Nationwide House Energy Rating Scheme (NatHERS) star rating (Australian Department of Climate Change and Energy Efficiency, 2011) than the control group. It was assumed that all housing met the Building Code of Australia (BCA) standard requirements through deem-to-satisfy provisions or the applicable minimum NatHERS Star rating at the time of development (Horne & Hayles, 2008). Design attributes which are said to define a building as sustainable are described on page 28 of this thesis in the Section titled, Sustainable Housing, Attitudes and Utility Consumption.

There is no consensus on what makes a home fully sustainable or how to measure such claims but efforts are being made to standardise operational and
embodied energy, resource and GHG type impacts (Cartwright, 2000, p. 72). Operational energy is defined as any energy that is used after the building has been constructed, whereas embodied energy is defined as the energy consumed by all of the processes associated with the production of a building (Australian Department of the Environment Water Heritage and the Arts, 2010b). The most common housing-related operational energy is electricity and gas consumption in kilowatt hours per household per day (kWh/household/day) and the energy focus of this study. The other major utility typically used to measure operational efficiency is water consumption per household per day in litres (L/household/day). Measurement of waste, transport and embodied energy (Troy, Holloway, Pullen, & Bunker, 2003) by looking at the components that went into the construction of the house, was not required to answer the study questions and hence fell outside the scope of the study.

Sustainable Communities

The United States President’s Council on Sustainable Development in 1993 offered a definition of sustainable communities as “healthy communities where natural and historic resources are preserved, jobs are available, sprawl is contained, neighbourhoods are secure, education is lifelong, transportation and health care are accessible, and all citizens have opportunities to improve the quality of their lives” (President’s Council on Sustainable Development, 1997, p. 1447). A more concise definition by the Institute for Sustainable Communities states “a sustainable community is one that is economically, environmentally, and socially healthy and resilient” (Institute for Sustainable Communities, 2012, p. 1). The Institute for Sustainable Communities describe such communities as aiming for a better Quality of Life for the whole community without compromising the wellbeing of other
communities, healthy ecosystems, effective governance supported by meaningful and broad-based citizen participation and economic security.

To achieve such outcomes many governments, housing developers and community groups have attempted to implement policies, regulations and covenants to support such changes in development practices. Such estates can be initiated by traditional developers ("pulling" the market) or active community based organisations ("pushing" the market). Each approach can often be differentiated by looking at which party takes most of the project risk. In the case of this research, the sustainable community of interest was developer-led, with the buyers of the blocks of land taking less of the infrastructure risk. Significant community engagement was attempted from early in the design by the developer.

In terms of previous research on sustainable communities, Srinivasan (2003) asserted that while some research suggests the built environment is having a negative impact on the environment, there is very limited research on the health benefits of sustainable communities.

Two sustainable community rating systems have been trialled in the United Kingdom (UK) and United States of America (USA). The UK BREEAM rating system for communities has been available since 2009 (BREEAM, 2012). The USA Leadership in Energy and Environmental Design (LEED) “neighbourhood” rating system opened in 2007, and has over 240 projects participating; however, no comparable study of their tangible outcomes has been completed to date (U.S. Green Building Council, 2012). LEED is one of the most widely used rating systems in the world and is often used in other countries which have not developed their own building rating system. Such rating systems provide buildings, hotels, schools, hospitals and communities, with a comparable benchmark, which when exceeded,
results in a certification that is a point of differentiation in the property market (Fenner & Ryce, 2008).

One study of 29 communities that had won accolades for sustainable design in the USA revealed some qualitative insights (Mapes & Wolch, 2011). It found that while in theory new sustainable communities include sustainable infrastructure and support different transport systems, culture, social structures and business opportunities, on the ground development goals and outcomes are often more limited. Other studies tend to focus on specific attributes only, for example, the pedestrian walkability of a community, which was found in a study titled “Walking the Walk: How Walkability Raises Housing Values in U.S. Cities” to be creating a premium of approximately $4,000 to $34,000 per house, compared to those homes with less than average walkable surrounds (Cortright, 2009). Consequentially there would appear to still be a knowledge gap between attempts to build more sustainable communities, and any benefits that may be derived from them.

**Technical barriers**

There are several barriers constraining moves towards more efficient and potentially Quality of Life enhancing housing environments. These include the cost of technologically superior materials, financial affordability, material shortages, lack of standardisation, lack of infrastructure, energy efficient technology limits, sustainable design knowledge and the quality of information (Rotherham, 2000). A key barrier would appear the ability of the house to deliver an acceptable indoor environment in terms of temperature, humidity, toxicity and light. Companies are also being accused of green-washing consumers with claims about excessive levels of environmentally sustainability, that are deceptive or misleading (Ha, 2007) creating some confusion in the market. Similarly rating systems, such as the Accurate family of thermal
performance rating tools for housing, have had their capabilities questioned but appear to be improving (Soebarto & Williamson, 1999).

Furthermore, energy production, and hence prices, are generally heavily subsidised by government (Morrison, 1995) which artificially protects the sector from advancement and results in inefficiencies. The cost of gathering reliable design and pricing information is still high, whilst incentives are scarce and evidence-based knowledge about where to put such “carrots” is missing. The minimum standards, such as building codes, are also held back by industry and consumer groups claiming to protect housing affordability (Downs, 1991). In addition, access to finance for environmentally focused improvements is limited and design processes are still based on traditional and inflexible processes (Levine et al., 2007).

**Non-technical barriers**

Human factors also influence our ability to enhance well-being and live more sustainably and these can be seen as often more difficult to measure and address. For example, beliefs and attitudes, which impact behaviour, are often harder to influence or change once ingrained (Arbuthnott, 2009). A perceived lack of time and different priorities are also likely to be constraints (Dearing, 2000). In addition, cultural norms can impact whole societies, for example the desire for green lawns regardless of climate conditions or the use of thermally inappropriate buildings in hot climates (Ignatieva, 2010). The methodology, used by the study to capture such impacts, is described in the next chapter.

The building industry is also fragmented, and split incentives prevent non-occupant owners from upgrading buildings. Split incentives occur when the benefits of changes do not go to the entity making the investment. This paradox leaves tenants and burdened with the often higher operational power, gas and water bills in
the absence of capital intensive (but holistically cost-saving) upgrades (Gillingham, Harding, & Rapson, 2012). Such financial and information gaps cause barriers that only risk sharing or more complex tripartite arrangements can address. Such schemes include Green Leases and voluntary environmental upgrade agreements (EUAs) and are becoming more popular to create the incentive and realise the benefits (Christensen & Duncan, 2010). Such benefits include lower operating costs for the tenants, reduced risk and access to capital and tax concessions for the owner. However, this has not been available to the residential sector, due to its greater level of building segmentation and higher quantity of individual housing owners.

Housing Performance

To date insufficient research has been conducted to quantify the operational performance of residential buildings incorporating ESD principles. There has been some work evaluating the performance of ESD “commercial buildings” (Stern, 2006), especially those achieving high environmentally friendly star ratings, proving that ESD commercial buildings can result in lower lifecycle costs and operational GHG emissions (Davis Langdon Consultancy, 2007). A further consideration is that, although the sustainable design of a building can perceivably assist in reducing water and energy consumption through passive measures, consumption efficiencies can also be impacted by the behaviour of the occupants within the home. The housing sector has come under criticism for being one of the largest contributors to greenhouse gas emissions (Dator, 2010). Thus, potential impacts of both housing design and occupant attitudes, values and behaviours need quantifying, to focus policy and funding on the areas that will make the most difference.

The need for research in this area is highlighted by government actions that have been actively encouraging sustainable development but this effort appears ad-
hoc in nature and could have limited input from research findings (Sutherland, Pullin, Dolman, & Knight, 2004). One type of Australian Government initiative has provided financial incentives to individuals, such as household rebates for the installation of solar panels and rainwater tanks (Solangi, Islam, Saidur, Rahim, & Fayaz, 2011). However, some of these schemes have failed quickly, suggesting there was a lack of planning behind them, for example the Home Insulation Rebate Scheme and Green Loans Home Sustainability Assessment Scheme (Gabriel & Watson, 2012; Sydney Morning Herald, 2010). Substantial changes to several solar tariffs have also occurred in recent years, suggesting a poor preparation and basis for some government environmental schemes (T. Nelson et al., 2011). Misdirected policies could potentially have a secondary impact on sustainable design, by misinforming the consumer about what makes something sustainable and where the real benefits can be obtained.

Similarly in a paper titled “Buildings don’t use energy: people do”, Janda (2011) argued that architects need to claim a leadership role, and do more than merely dictate built architectural forms. Janda suggested architects should use their personal expertise to integrate user involvement into buildings, so they understand, are given capabilities and can make direct environmental savings. Hence it would appear gaps in current policies and professional skill sets are impacting people’s ability to live more sustainably. Consequently, the study had research objectives which included measuring the operational performance of sustainably designed homes. This was achieved by measuring building performance, via levels of utility consumption, as per the approach by the National Building Energy Rating System (NABERS).
To date the building industry has focused on the technical aspects of housing performance (Australian Building Codes Board, 2012; Jiboye, 2011; Newman & Kenworthy, 2006) however it is reasonable to expect human factors to also play a role (Heerwagen & Zagreus, 2005; Janda, 2011). In terms of the more physical measures of building performance, the design and technology are frequently the focal point, and such aspects are arguably easier to measure than occupant/behavioural impacts. Building design factors can include its orientation, materials, building codes and climate. The technical aspects can involve heating and cooling systems, building management software, appliances and systems used to design the building. Often, modelling is completed using simulation software to predict how a building will behave, but this is done less frequently in the residential sector than in the commercial sector.

Non-Technical Housing Performance

Several non-technical factors perceivably impact building performance, including psychological, cultural and social aspects (Heerwagen & Zagreus, 2005; Preiser & Vischer, 2005). For example, if there is an air conditioner in a room, but the occupant is opposed, for belief-based reasons, to using the (extra) energy required to operate it and cool themselves on a hot day, then this may reduce the home’s total energy consumption. It is interesting to note, however, that if the occupant could not make alternative adjustments to cool themselves (for example if the room did not have windows to encourage cross-ventilation) then they could report lower levels of satisfaction, and this would not be due to the lack of technology.

Many design features have the ability to affect attitudes and resource consumption (Herring & Roy, 2007). Yet rebound effects include people using an
efficient appliance more often or having longer hot showers after installing a solar hot water system. These outcomes suggest we need to make humans part of the solution rather than just identifying them as the problem, and also that unintended policy consequences can occur without adequate research in advance (Binswanger, 2001).

Consequently the present study attempted to evaluate such impacts, by measuring occupant attitudes, as a proxy for occupant behaviour which is affected by such psychological, cultural and social factors (Bandura, 2001). As discussed previously, this wider scale of thinking can potentially provide support for a more environmentally aware Quality of Life (QoL) model.

To provide context, the next section describes the environmental relationships to Quality of Life, and living (more) sustainably. Our current knowledge about the major study components; sustainable housing, occupant behaviour and resource use, is then set out.

Environmental Relationships with Quality of Life
The wider problem of how to maintain perceived well-being whilst reducing environmental impact is a multi-disciplinary challenge (Herath, 2005). Questions such as what makes “environmentally friendly” housing truly sustainable, and whether such changes also improve “Quality of Life”, are also often debated (Bramley & Power, 2009). It has previously been suggested that items critical to the debate have been under-represented, including population, scale, displacement, value judgements, efficiency and space (Mawhinney, 2002); and that one change to seemingly reduce impacts, should not be made at the expense of another. For example, increasing or decreasing housing density should not occur without a
strategy to support the educational, health, food, transport and employment needs of residents (Steemers, 2003).

Brundtland stated in a closing ceremony address for World Commission on Environment and Development in 1981 that several principles were required to promote sustainable development including that “growth must be of a kind in which sustainability, equity and social justice and security are firmly embedded as major social goals... a safe, environmentally sound energy pathway is an indispensible component of this” (Brundtland, 1987, p. 9). This statement supports calls for more detailed analysis of solutions that are likely to deliver positive social and energy outcomes (Hartmann & Ibanez, 2006).

To date there has been a range of different theoretical and empirical approaches to determining environmental impacts on Quality of Life (Gatersleben & Vlek, 1998; Poortinga, Steg, & Vlek, 2004). Many of the Quality of Life or “liveability” studies undertaken throughout the world have been pitched at a regional or higher level (Wang, Su, Chen, Chen, & Liang, 2011). Hyde (2006) concluded that “a major gap... exists in understanding at the level of the precinct and community... the problem is to differentiate structural and local determinants of quality and satisfaction from those operating at higher spatial scales” (p. 1). Without such segregation it could be argued that it is not possible to ensure that sustainable policies are not impacting the quality of people’s lives unintentionally.

There are numerous examples of general Quality of Life studies worldwide, but few have been able to combine biophysical and ethnographic measures. Wandersman and Hallman (1993) suggested that “to respond effectively to environmental problems, policy makers must know as much about the social, emotional and behavioural impacts of environmental threats as they do about the
biological effects” (p. 681). Indeed society’s focus since early last century on urbanisation and economic growth has resulted in a new competing QoL paradigm which suggests that people should be focusing on community development rather than individual satisfaction levels to achieve more holistic and higher average levels of satisfaction (Sampson, 1991). Such a QoL paradigm differs from the industrial paradigm of maximizing output and suggests that efforts are best focused on the community as a target of development (Hyman, 1994). It has also been argued that authorities could spend more time educating people about their internal ability to make themselves happier, rather than relying on material wealth to do this (Wadley, 2010).

Models of sustainable development such as Balance Theory (Mawhinney, 2002) suggest that QoL can be maintained or improved through the integration of social, economic and environmental needs. Unfortunately there are few tools available for the planning and design of precincts to improve sustainability and reduce environmental impacts of a development (Hyde et al., 2005). However, so called “green” rating tools such as the United States LEED Neighbourhood Development Rating System, UK BREEAM Communities tool and the recently released Green Building Council of Australia’s Green Star for Communities tool are assisting with this endeavour (Ding, 2008).

In order to compare the communities and meet the wider project objectives, additional models and indicators needed to be analysed and selected. As an example, after evaluating various studies on Quality of Life indicators, Gatersleben and Vlek (1998) were able to derive a set of 15 major social indicators to study Dutch households in 1997. These indicators were social relations, education, comfort, pleasure, beauty, labour, health, privacy, money, status, safety, control, leisure,
justice and nature/environment. One of the Dutch study’s conclusions was that householders were probably not aware of the indirect energy consumption of their household, as embodied in the goods they owned. Also, they found most Dutch consumers on average believed that it was necessary to change most household and consumer behaviours to limit environmental impact, but that this understanding failed to relate to their own actual behaviour.

New models of QoL have evolved using a “principles to indicator” approach with a broader set of factors including the social, economic and environmental aspects (Mawhinney 2000). The new framework of sustainability examines QoL from a range of scales including region, city and neighbourhood and also provides new methodologies for understanding the phenomenon. The holistic model could offer a richer information base to facilitate policy formulation for the planning and design of particular aspects of regional infrastructure such as neighbourhoods and precincts. However, to provide more quantitative research to test the new models, more studies are required to test the theories (Lamborn, Altomonte, Luther, & Fuller, 2006). The present study examines utility usage and attitudes within theoretically more sustainable and less sustainable communities, thereby providing an opportunity to better understand QoL perspectives that incorporate environmental factors.

Moser (2009) proposed that “people’s relationship to their own living environment is a crucial issue for understanding their personal well-being and quality of life” (p. 355). Previously Sun (2005) has derived a suite of indicators for Saskatoon neighbourhoods and found they allow comparison between neighbourhoods by assessing their relative strengths and weaknesses. Sun (2005) concluded that while the development of a neighbourhood QoL indicator system
would greatly benefit cities, some issues, such as how best to characterize the indicators and how to incorporate subjective measures, require more attention. The Saskatoon study suggested that neighbourhood Quality of Life indicators are a means to “measure and monitor specific attributes as well as neighbourhoods’ overall liveability, which can help achieve the goal of building a healthy community. Use of such indicators also allows the making of comparisons among neighbourhoods to identify their comparative advantages and potential problems” (Sun, 2005, p. 4). However, data about specific design types and consumption levels are required fully to evaluate impact on the environment, relative to any liveability/satisfaction levels encountered, to allow identification and tracking of unsustainable behaviour. To this end, analysing consumption in this context, it is important first to understand the relative impacts of consumption, as targeted by the present study.

Trying to address housing impact issues, whilst managing new affordability pressures makes the challenge to address climate impacts even greater. Affordability is part of any sustainable solution and without affordable options, the gap between richer and poorer increases, resulting in inequity and pressures on land use and family structures. Indeed, the recent economic pressures resulting from the Global Financial Crisis of 2008 have seen land block sizes decreasing in the study area, south-east Queensland, with developers needing to sell land for lower prices than previously, to meet the market (Rossiter, Greig, & Anson, 2011). As a result, homes can decrease in size rather than increase, which would create a different trend for the Australian property market. Smaller homes are likely to be more affordable but, unless personal expectations change, more land becomes available or higher density (multi-unit) development occurs, prices might not drop to meet affordability targets.
Similarly, the lack of knowledge about the benefits of more efficient/sustainable housing in the longer term is not considered when constraining the initial capital cost is made a higher priority by the investor. Also, an occupant’s quality of life could be impacted by a house built with a focus on lowering (only) the initial capital cost (Langston, 2012). Over time, other factors could easily affect the occupant, including higher electricity or water costs due to the less efficient design, lower quality structures, lack of appropriate ventilation and cheaper (often toxic) materials that impact indoor air quality and hence health. Ecologically sustainable design aims to address such issues by using sound principles such as solar passive design to reduce heating and cooling needs, more natural products to reduce volatile organic compounds (VOCs) and other safety and adaptability opportunities.

Framework

If the problem being targeted is anthropogenic climate change and sustainable development can help to address this issue, then we need evidence about the most appropriate solutions and how to implement them. Similarly, we need evidence to show what impact such solutions have on Quality of Life, as a measure of well-being, and that ensure any market changes also enhance (or at a minimum maintain) existing Quality of Life levels. Without such evidence, change could be rejected as being too difficult or costly (Farber, 2009). This study addresses part of the wider issue and focuses on trying to understand the data from predictors of environmental impacts of the residential sector, through sustainable housing analysis.

To provide insights on Quality of Life, which require measurement of social paradigms, an additional social survey on neighbourhood satisfaction was conducted, as part of the wider project. It is reported on by Anir Upadhyay, who advanced results of the present study. A model of the factors of perceived
relationships for context is shown in Figure 1 below and is an adaptation of models proposed by Upadhyay, Hyde and Wadley (2010). The resulting impacts by the environmental factors assessed by the wider project, it is proposed, can then be termed an environmentally influenced Quality of Life (QoL_e).

![Conceptual environmental focused Quality of Life model](source: adapted from Upadhyay, Hyde and Wadley (2010))

The framework suggests that human attitudes and external environmental factors (model inputs) are influenced by behaviours, perceptions and person-environment interactions (mechanisms). And the combination of these can then be evaluated to
see if psychological needs of relatedness, competency and autonomy are achieved (outputs), which Deci and Ryan argues would result in higher levels of well-being (Deci & Ryan, 2008; Ryan & Deci, 2000). This continuum ranges from non-self determined behaviour to extrinsic motivation, to intrinsic motivation (i.e., self-determined behaviour) (Milfont, 2007). Ryan and Deci’s model attempts to extend Maslow’s work, through a self-determination theory of human motivation (Maslow, 1943). The present study focuses on the residential housing environment and aims to test parts of the conceptual model.

The model’s mechanisms propose that the level of people-environment interaction impact determines the amount of self-determination, and eventually an individual’s level of well-being. It is also claimed that high people-environment congruity often purport to have a higher Quality of Life (Moser, 2009) and it is proposed that sustainable housing could enhance such connections. It appears that most sustainable communities aim to provide greater levels of well-being, through additional services and facilities and intentional connections (Barton, 2000). Hence if a sustainable community can perceiveably provide high levels of satisfaction, whilst lowering utility consumption, then such infrastructure and design would appear to be part of the answer to address climate change impacts without undesirable quality of life impacts. It should also be acknowledged that these factors overlap and potentially enhance each other. For example, providing an environmentally aware person with additional capacity to use less energy, share a pool or attend dance classes weekly inside an intentionally sustainable community could enhance their well-being as well as reduce costs and their impact on the environment. Furthermore, the resulting effects could be magnified due to the massing of people with similar goals and ideology.
In the past, sustainable development has targeted and been evaluated for environmental, social and economic influences (Barton, 2000; Giddings, Hopwood, & O'Brien, 2002). However, this lacks focus on the “individual” (Levett, 1998). Similarly, technology driven approaches to achieve sustainable outcomes obtain higher priority compared to holistic approaches which can take account of the individual and triple bottom line considerations (Upadhyay et al., 2010).

In terms of measuring sustainability holistically, assessment criteria can be described as widely as: technical (water, materials and energy); environmental (system operation and infrastructure); economics (capital and operating costs, revenues); and social impacts (Fagan, Reuter, & Langford, 2010). To answer the research questions, the present study focused on the technical results of house operation. NABERS measures house performance through energy and water data and the present study used these same operational performance measures (Australian Department Environment Climate Change and Water, 2010). Economic cost related data were not sourced as the hypotheses required only biophysical data. Waste, materials, transport, indoor environment quality and embodied energy were intentionally excluded from the scope of the study because these resources were not relevant to the study specific hypotheses. In order to evaluate how the sustainable design and individual behaviour relatively impact utility consumption levels, measurement of occupant attitudes was included. These major variables are now described below.

Sustainable Housing, Attitudes and Utility Consumption

This section describes the variables used in the study to test the hypotheses, namely the sustainable housing and occupant attitudes (independent variables) and the types of utility consumption (dependent variable).
As defined on page 11, "Ecologically Sustainable Design" is a relatively new term that has been gaining attention mainly due to the increasing cost of resources such as energy, which has driven those paying utility bills to find methods to maximise efficiency. Because the term and concept are relatively new, studies focusing on the sustainable design of housing on a precinct large scale are not yet common although a few such studies exist (Mulder, Costanza, & al, 2006; Schnieders & Hermelink, 2006). Some have indicated that other factors can provide the glue to maximise benefits and that this is often lacking even in intentionally more sustainable estates and these described below (Barton, 2000).

Precinct Level Studies

Residentially, focused studies have suggested that residents of “intentional communities”, such as communities that emphasise sustainable design, arts or religion, are capable of supplementing built capital with social capital and hence can reduce total resource usage and dependence (Clark, 2009; Mulder et al., 2006). The present study supplements this research with more extensive data and follow up interviews will enable qualitative comparison with similar previous work, for example four sites studied by Hostetler and Noiseux in Florida, USA in 2006. Hostetler and Noiseux initially found that residents did not come equipped with the environmental knowledge, attitudes and behaviours to make green communities function and later suggested post-construction management and educational programs to engage residents of green communities (Hostetler & Noiseux, 2010). A gap in the 2006 study was consumption measurement, whereas the present study obtains and analyses such data through utility usage. To determine the causes of lower utility usage, the present study seeks to understand if people in sustainable
homes who have pro-environmental attitudes and beliefs are capable of practising low energy and environment friendly behaviour and maximising the passive sustainability features of their home through operational influences. The attitudes survey also attempted to capture occupant data to evaluate whether occupants were people who may have been trying to take personal responsibility for their environmental impacts, as this would also change their values and hence attitudes as well (Shove, 2010).

*Sustainable Housing Attributes*

There are many sustainable development and design frameworks and rating systems that define characteristics that claim to make buildings more sustainable. One example is the Your Home Technical Manual commissioned by the Australian Federal Government (Australian Department of the Environment Water Heritage and the Arts, 2010a). Key sustainable design attributes covered in this guide are summarised in Table 1 below.
Table 1 - Common sustainable housing attributes

<table>
<thead>
<tr>
<th>Category</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>The value of appropriate site selection, rating systems, and housing systems and development history.</td>
</tr>
<tr>
<td>Design for life</td>
<td>Encouraging adaptability, healthy homes, biodiversity, safety and security.</td>
</tr>
<tr>
<td>Passive design</td>
<td>Designing for the local climate and maximising orientation; solar passive heating and cooling, the importance of thermal mass and insulation and glazing.</td>
</tr>
<tr>
<td>Material use</td>
<td>Waste and embodied energy minimisation, natural materials, longevity, resilience, availability and recyclability.</td>
</tr>
<tr>
<td>Energy use</td>
<td>Heating, cooling, appliances, renewable energy and automation.</td>
</tr>
<tr>
<td>Water Use</td>
<td>Reducing demand, efficient appliances, water reuse and irrigation.</td>
</tr>
</tbody>
</table>

Source: (Australian Department of the Environment Water Heritage and the Arts, 2010a).

Residential building “occupants” are not yet commonly identified as key drivers of more sustainable outcomes, for example to maximise possible attitudinal and resulting behavioural impacts (Baird, 2009). This gap provided an added reason to include occupant attitudes in the current study. Some commercial-building rating tools include occupant education and management categories to address this potential opportunity, such as the Green Star design rating tools (Green Building Council of Australia, 2012a). However, there is limited research on behaviourally focused housing policies and incentives in the residential sector.
Housing that is designed to follow such principles and/or contains such attributes, as mentioned above, is often called sustainable housing and a variety of rating systems are available to estimate, measure, predict and promote such housing (ARUP, 2004). For the purposes of this research, the study group contained such features as described below in the section titled “Sustainable Design: the Study Group Housing and Environment”.

Several studies have been able to highlight the benefits of particular sustainable design attributes, but the combined effect has been difficult to study objectively (in isolation) due to the additional environmental impacts that affect the broader sustainability outcomes. A snapshot of claims of Green Building specific benefits includes:

a. 4.8% higher annualised returns for Green Star rated CBD office buildings compared to non-rated buildings, as reported by the IPD Property Index (Investment Property Databank, 2011a)
b. Lower capitalisation rates for NABERS Energy rated buildings (Investment Property Databank, 2011a)
c. Occupancy ratio increased by 3.5% (McGraw-Hill Construction, 2007)
d. 19% increase in average student oral reading fluency scores when compared to the prior, conventional school; reported by a PhD study (Doll, 2005)
e. Reduced student absenteeism (72% of survey respondents from green schools), improved student performance (71%) and better health and well-being of occupants (88%) (Turner Construction, 2005)
f. 30% lower operating expenses for Energy Star buildings (N. Miller, Spivey, & Florance, 2008).
Some sustainable building rating tool organisations and developers have also developed Green Building business cases in an attempt to communicate such benefits, namely The Dollars and Sense of Green Building (Green Building Council of Australia, 2006), The cost & benefit of achieving green buildings (Davis Langdon Consultancy, 2007) and The Green Star - Communities Business Case (Green Building Council of Australia, 2012b). More attention is now being paid to macro level sustainable design and planning of cities and towns, but how to measure their sustainability is contentious (Campbell, 1996; Margolin, 1998).

Differences at the more micro level of individual housing are more readily definable and accessible, where such explicit examples can be sourced. To evaluate the differences in housing with and without sustainable design attributes, this study focused on house design, the occupant’s attitudes and the energy and water (utility) consumption of the housing, for two distinct but well defined sub-divisions (estates), as depicted in Figure 2.
When measuring attitudes, the study is making an assumption that attitudes are liked to behaviour and in essence, the study is using attitudes as a proxy for behaviour. To identify the relationships between the components that can be studied and those factors that cannot refer to Figure 3.
As we have covered (sustainable) house design characteristics earlier in this chapter, hence for completeness, a review of occupant attitudes research is detailed below, followed by the dependent variable (utility consumption).

**Occupant Attitudes**

In understanding influences on environmentally favourable behaviours, both attitudes and behaviour need to be considered. In the present research, the focus was on attitudes rather than behavioural measures. However, an advantage of the present design in comparison to a large proportion of research on environmental attitudes
was the inclusion of direct utility consumption measures that would have been at least in part a product of the occupants' behaviour.

Consistent with prominent conceptualisations of attitudes in behavioural research literature, an attitude was defined in the present study as a positive or negative feeling about taking a specific action (Fishbein & Ajzen, 1972). Also, in line with relevant research and theory is the assumption that attitudes regarding actions tend to be correlated with the relevant behaviours, but the correspondence between attitudes and behaviours is less than 100% (Fishbein & Ajzen, 1972). The development of an understanding of an issue, product or service is perceived to be dependent on learning, and behaviour is shaped by values and knowledge (Kaiser, Wölfing, & Fuhler, 1999). Both attitudes and behaviour are most frequently measured by self-report. Similar to attitudes, self-reported behaviour also has a less than 100 per cent correspondence with objectively observed behaviour.

In relation to the provision of incentives to change behaviour in commercial buildings, recent research into the performance of 31 Green Buildings by researchers at Bond University (Hikari & Murugan, 2011) showed that leading organisations were providing guidance and incentives for staff to act in environmentally beneficial ways. These results have highlighted the importance of incentives to motivate behavioural change.

Several different projects have demonstrated that, specifically, Environmental Attitudes (EA) are associated with ecological behaviour (Kaiser et al., 1999; Martíimportugués, Canto, García, & Hidalgo, 2002). For example, a study, of drivers who had joined “Green” car associations found significant correlations between pro-environmental attitudes and pro-environmental behaviours (Grob, 1995). A study of “Green” consumers from Queensland also found significant
associations between pro-environmental attitudes and environmental behaviours (Gadenne, Sharma, Kerr, & Smith, 2011). In a study by Balderjahn in West Germany (1988) more pro-environmental attitudes (for example, wanting to reduce pollution) were found to be significantly associated with using less heating and taking showers instead of baths. Positive environmental attitudes were also significantly associated with buying and using non-polluting products and with driving in more environmentally responsible ways (for example, minimising driving or using alternatives to driving).

A further field study involving 120 household in the United Kingdom found environmental attitudes were not associated with energy consumption before the intervention, but they were influential in reduction of household energy use when given feedback. Results also indicated that income and demographic features predicted historic energy consumption but not changes in consumption during the field study. In the study, feedback groups suggested comfort and expenditure were important motivators with regard to levels of energy use (Brandon & Lewis, 1999).

A review of studies trying to change behaviour in 2005 revealed that underlying determinants of attitude and knowledge are generally positively related to energy savings (Abrahamse, Steg, Vlek, & Rothengatter, 2005). It is therefore likely that strong conservation values in residents toward environmental conservation will impact on relevant behaviour and, in turn, resource usage (Bonaiuto & Bonnes, 2010).

Household behaviour of occupants can be quantified using relevant measures such as their actions to reduce power and water usage. Examples include turning appliances off when not in use or putting on more clothes before turning heaters on. In 2006, the Environmental Attitudes Inventory demonstrated that
attitudes that favoured environmental preservation predicted self-reported ecological behaviour, whereas those favouring higher utilisation of resources predicted behaviour toward economic liberalism (Milfont & Duckitt, 2006). Similarly, meta-analysis has previously demonstrated a significant correlation between environmental attitudes and behaviour (Hines, Hungerforda, & Tomerab, 1987). Measurement of attitudes via a scale provides a less intrusive monitoring tool than direct measurement of occupant behaviour. It is argued that the environmental attitude of the respondents is connected to their behaviour, through their ability to perceive their “own impact” on global energy consumption levels.

In 2002 a study in the United Kingdom examined the divide between energy saving behaviours in the home, relating to purchase-oriented behaviours and habitual action to save energy (Barr, Gilg, & Ford, 2005). The findings suggest that generalisations about groups that conserve energy are hard to make as they vary considerably based on social composition, values and perceptions. Hence for the present study, care must be taken if assuming what is actually causing any differences in energy consumption.

Similar studies have investigated associations between energy use and attitude or energy use and the design of housing (OECD, 2008). Some past studies have also explored the determinants of a specific consumption domain such as energy, water, travel, appliances and housing (OECD 2008b). The present study investigates both types of associations, using the same sample which allows for improved control and recognition of external variables and other influences such as climate, household size, lot site, occupancy and house size. It focuses on primary utility consumption (electricity and water) and takes into consideration the size of the home, the amount of time the houses were occupied, and the number of people in
each house, which impose both direct and indirect environmental pressures on natural resources (Dey et al., 2007). The two groups of homes in the present study were located in the same area, so that climate was held constant. Factors, including climate, housing characteristics and social differences have been shown to influence utility consumption (Lenzen, Dey, & Foran, 2004) but no significant correlations with any attitudes, beliefs or intentions were elicited from respondents of a 2008 study (Kristrom, 2008).

To assess existing local environmental attitudes, Australia Bureau of Statistics reports were analysed. Attitudinal survey data demonstrates general concern about the environment in Australia, which could be influencing householder behaviours. National data showed that, in 2007-08, 82 per cent of Australian adults reported that they were concerned about at least one environmental problem. Twenty-six percent reported believing that the condition of the natural environment was “bad” while almost two-fifths (39 per cent) felt that it was “neither good nor bad”. Nevertheless, over half of adults (53 per cent) said they thought the natural environment was “declining” (Australian Bureau of Statistics, 2010b). Of the 12.9 million adults who reported that they were concerned about the environment, nearly three-fifths (59 per cent) reported that their water consumption had decreased, compared with two-fifths of those who were not concerned. Of the 8.7 million Australians who reported that their water consumption had decreased, over three-quarters (76 per cent) said it was because they were trying to conserve water at home and over two-fifths (42 per cent) attributed it to water restrictions being imposed or increased (Australian Bureau of Statistics, 2010a).

In addition to general environmental attitudes, attitudes relating specifically to household utility use were also examined. Macro studies of quality of life showed
approximately 91% of Queenslanders surveyed in November 2001 said they were "satisfied" or "very satisfied" with their quality of life. Despite this positive outcome, a number of the existential factors such as money, health, crime and jobs point out a lack of capacity in infrastructure to meet the needs of an increasing population. For example, indicators have demonstrated a sharp decline in housing affordability (Queensland Government, 2011) which, as previously discussed, must be considered when trying to provide sustainable housing solutions. In the present study, construction and land costs were considered outside the scope but further research could analyse cost differences of houses, inclusions and land for these populations.

The Australian Bureau of Statistics also reported that there has been an increase in the number of adults who said that they were influenced by environmental factors when considering their household energy as was demonstrated in self-reporting of both attitudes and behaviour, for example:

"in 2008, energy efficiency was the most common factor considered by Australian households when replacing or buying most white good appliances compared with 2002, when the most common factor considered was cost. Nearly three-quarters (74%) of Australian households used cold water rather than warm water in washing machines, up from 61% in 1994. And, between 2005 and 2008, the proportion of households who used energy saving lights increased from 33% to 59%". (Australian Bureau of Statistics, 2010b, p. 4)

However, there was also a significant increase in households which had mechanical air conditioning, more than doubling from 32% in 1994 to 67% in 2008 (Australian Bureau of Statistics, 2010b, p. 4); sustainably designed housing attempts to minimise mechanical air conditioning.
In regard to personal comfort, it appears that it is an increasing high priority for residential occupants. The Australian Bureau of Statistics reported in 2008 that 61 per cent of homes had insulation, compared with 52 per cent in 1994. The main reason for installing insulation in a house was “to improve comfort” (83 per cent of households that installed insulation), whereas “to save energy” was reported as the main reason by only 4 per cent of households with insulation (Australian Bureau of Statistics, 2008). This figure suggests that conserving energy is still not a priority for most Australians, whereas protecting or improving their living conditions is highly valued. However, the data also showed that the energy star rating of an appliance was frequently rated more highly than price when consumers were replacing or buying items including a refrigerator (50% of consumers ranked energy star rating as more important than price), separate freezer (46%) and clothes dryer (45%) (Australian Bureau of Statistics, 2008).

Similarly, in 2008 one-third (32%) of households were aware of the Australian Government’s renewable energy label (GreenPower) and were willing to support the scheme, suggesting many Australians were environmentally aware and concerned (Australian Bureau of Statistics, 2008, p. 8). Other research (W. P. Newton & Meyer, 2011b) has shown that people struggle to turn these concerns into action, due to a variety of barriers including:

- a lack of relevant information and knowledge of where to find it.
- organisational challenges, that is, identifying the best options from alternatives, and contracting to get the work done.
- time constraints and other competing priorities.
- financial constraints and determining the financial outlay and return on investment.

A government approach has been to attempt to reduce barriers to sustainable development. Initiatives in south-east Queensland have aimed to address six such
barriers; namely, disincentives in the fiscal system; perceived higher costs; lack of consumer demand; lack of investment interest by developers; no agreed standards; and a planning system which does not support sustainability (Wheeler, 2003).

Newton and Meyer concluded that "on the demand side, comfort, convenience and cost factors seem to underpin many of the habits and practices that currently promote consumption of urban resources in Australia; and there remains a lack of information on what can be done and how best to get it done" (2011b, p. 288). Such findings provide reasons for potentially reduced relationships, or even a lack of correspondence, between environmentally positive attitudes and relevant behaviours or outcome measures. Hence this study has included attitude, design and consumption variables.

Experiences from the United Kingdom have shown that liberalised energy policies have resulted in more consumer choice regarding energy but that this has not been matched with policies to reduce energy use; subsequently, increased household GHG emissions have been recorded. Previous research that focused on demographic variables in relation to energy has been criticised for its failure to consider broader issues such as individuals' cognitive abilities, values, attitudes, and external factors such as social networks, marketing, and products and services (Faiers, Cook, & Neame, 2007).

The data from a Norwegian study showed no statistically significant difference in private energy consumption per year between respondents with positive environmental attitudes and other respondents (Holden & Linnerud, 2010). These authors concluded that people who claimed to be environmentally conscious did not behave in a more environmentally friendly way in relation to their energy consumption compared with other people. Similar lack of association was found in
two previous studies by the same first author (Holden, 2004a, 2004b). Holden proposes that there are at least three mechanisms that influence whether households are able to behave in an environmentally friendly way: a desire to project an environmentally friendly image, a desire to self-indulge, and a sense of powerlessness. In their opinion, information campaigns to increase people’s environmental awareness have very little effect on the level of energy use in the home. Holden, however, reminds us that that domains other than domestic energy consumption offer additional opportunities to influence people’s attitudes and encourage environmentally friendly solutions. As a result the present study used questions inside a survey to try and capture such influences.

Contrasting results from several major surveys conducted by Norway’s National Institute for Consumer Research in 1996 demonstrated clear links between respondents’ level of environmental awareness and behaviour such as sorting waste for recovery, taking environmental considerations into account when shopping, and choosing ecological food products (Lavik, 1997).

An earlier study in 1978 claimed household occupants’ behaviour is a significant determinant of actual energy use. It was calculated after studying gas consumption, that 54 per cent of the variation of energy consumption was attributable to the building envelope and suggested that the remaining 46 per cent was for occupants’ behaviour and other non-physical factors. The research claimed that 71 per cent of the variation of energy consumption was due to differences of household internal temperature, mechanical ventilation, and airing through windows and doors, while 29 per cent was due to the house’s construction. Closer scrutiny of the consumption data speculatively suggests “that the 71% are the sum of 33% non-persistent patterns (change) and 38% persistent, occupant-related patterns (lifestyle)”
Sonderegger claimed to have proved experimentally that “unpredictable behaviour patterns of the occupants introduce a large source of uncertainty” in residential space heating energy requirements (p. 323). However, this study only measured heat loads and not other sources of energy consumption, including lighting, pool pumps and appliances such as air conditioning which are now becoming a standard feature in new homes today. Hence, the results could have originally been skewed and would now appear inappropriate to compare against housing built in the last three decades and attitudes which are also likely to have changed.

In regard to climate impacts on energy use, a Norway study that used a statistical simulation method based on the Monte Carlo technique suggested that “variation from inhabitants is much more significant than variation from climate” (Pettersen, 1994, p. 1). As a result it would be important to estimate the variation attributable to inhabitants’ behaviour. The modelling suggested that, if the inhabitants' behaviour is unknown, it is impossible to predict the total energy consumption more accurately than ±15–20%, compared with the consumption found with traditional energy calculation methods. The heating and ventilation energy consumption is encumbered with an uncertainty of ±25–40% if the inhabitants’ behaviour is unknown. Hence, it could be more appropriate to conduct further research to reduce this uncertainty so the impact of updated standards and incentives can be more accurately predicted and hence targeted.

In conclusion, relationships between attitudes and actual behaviour may be tenuous and this point needs to be considered in any study evaluating attitudes. Similarly, although people often report concerns about the environment, they do not necessarily translate into actions, or measurable or effective change. In terms of
credible literature, some research on attitudes and utility usage in the residential context is available; however it is rarely compared in the same study together. The research described in this thesis aimed to combine these aspects. Also, previous research appears never to have distinguished between the designs of the homes (in the context of a house being designed in an attempt to make it more sustainable) in combination with utility and attitude force. This gap was considered worthy of specific investigation. Utility consumption was measured to analyse the impacts of homes with sustainable design attributes (or not) in combination with occupant attitudes, which we hypothesise, influences their operation of the house, and this dependent variable is described in detail in the following section.

**Utility Consumption**

A number of domains need to be considered when examining residential environmental impacts in terms of utility use including: relative residential sector energy and water use, prior research on utility use in (commercial and residential) buildings, and the behaviours of individuals. The objective of the next sections is to examine these domains. Previous studies could not be found comparing many of these particular impacts, specifically for different types of housing design; however those that were found are highlighted below.

**Utility Consumption of Commercial Buildings**

Unlike the residential sector, to date there has been significant research evaluating the energy performance of commercial buildings in relation to sustainable design features (Stern, 2006). This absence would appear to be due to the larger scale of the buildings, access to data and the focus on financial returns on investment in the commercial sector. For example, as noted earlier, commercial buildings which
achieved high star ratings in standardised sustainability assessments were found to have lower lifecycle costs and lower operational GHG emissions (Davis Langdon Consultancy, 2007). The Investment Property Databank’s Green Property index found that from 2008-2010, Green Building Council of Australia Green Star rated office buildings performed better on average than non-rated buildings, with the highest return being for a 4 Star rated building at 8.7 per cent, for annualised income and capital, 2 year returns, compared with 1.6 per cent for non-rated buildings. In terms of operational energy performance measurement tools, NABERS scheme results demonstrate that on average, offices rated 4 Stars or greater yielded higher returns with up to 5.4 per cent annual return for a (maximum) 5 Star rated building compared with a 1.6 per cent annual return for an non-rated building (Investment Property Databank, 2011a). As such it would appear that the Australian commercial sector now has sufficient data to justify some of the financial benefits of green buildings.

In the United States of America, a green building rating tool known as LEED has been available since 1998 (U.S. Green Building Council, 2003). In 2009, the Grand Victoria Foundation compared a total of 25 commercial buildings and found LEED-rated buildings that focused on energy efficiency measures, were likely to be more energy efficient than rated buildings that did not (Grand Victoria Foundation, 2009). However, the report suggested that only a larger sample size would confirm a statistically significant association. The study also found a wide variation in LEED rated building results and recommended further research be undertaken to identify the reasons for the variation. A related study of LEED-rated commercial buildings found 11 cases which on average used 25-30 per cent less energy than the national average (Turner, 2008). It also found that on average, LEED-rated buildings were
delivering their anticipated financial savings but that some types of predicted savings were not eventuating. In regard to GHG emissions, commercial green buildings have been shown to reduce emissions by 34 per cent on average compared with typical buildings (Fowler, Rauch, Henderson, & Kora, 2010) which suggests such building principles are likely to be a powerful way to address climate change.

The residential sector, discussed further below, in turn is typically made up of houses that are developed by builders with no incentives to maximise operational utility savings or occupant well-being, which are only realised after the building phase is completed. Houses are generally then owned by individuals and investors who do not have the ability, time, knowledge or incentive to investigate or maximise such benefits. Hence new research on such opportunities is critical, if we are to understand how (if at all) residential sustainably design attempts impact the environment.

**Utility Consumption of Residential Buildings**

International research by the Branz company studied energy use in 300 conventional homes in Auckland, New Zealand from 1996 to 2006 and compared the outcome with previous data from the early 1970s (Camilleri, 2006). However, the Branz research did not examine energy in sustainable homes or compare or rate the designs of the homes themselves. The study found that average household electricity use from 1996-2006 (7,900 kWh/yr) was similar to 1971-2 (8,400 kWh/yr) but that the main three end-uses of electricity had shifted considerably from the pattern found in 1971/72, due mainly to an increase in consumer appliance usage, namely air conditioners, computers and other electronic devices. There was also a significant increase in liquefied petroleum gas (LPG) fuel heater use compared with the historical data. From 1990 to 2005, energy consumption by households has
increased 23 per cent and this trend is expected to continue as shown in Figure 4 – Total Residential Energy Consumption from 1990 to 2010.

A study of college students in the USA found the introduction of feedback, education and incentives resulted in a 32 percent reduction in electricity use and only a three per cent reduction in water. Students who were given high resolution feedback via a computer based system were more effective at reducing their energy consumption, reducing it by 55 per cent (Petersen, Shunturov, Janda, Platt, & Weinberger, 2007). A similar exercise was also completed at Bond University for a block of resident students resulting in a reduction of energy consumption (Uncles, 2012). This demonstrates that with the right information, people’s behaviour can be changed and result in meaningful reductions in energy consumption. Such projects
triggered the creation of the monitoring system now installed in most study group homes.

In the Australian context, heating and cooling accounted for the greatest proportion of energy consumed in households (almost 40%) in 2006-07. This contributor was followed by water heating (25%), household appliances (19%), lighting (6%), and cooking (6%). Of household appliances, refrigerators and freezers were the largest contributors to energy use, consuming 34% of all energy used by household appliances (Sandu & Petchey, 2009). The residential sector accounted for about eight per cent of Australia's total energy use in 2006–07 (Australian Bureau of Statistics, 2008). Hence there appears to be an opportunity to reduce energy use, specifically focusing on house design and appliances.

From an investigation of five award winning detached residential houses, Williamson has found that homes were not as energy efficient as intended (T. Williamson, Soebarto, & Radford, 2010). The study was able to show deficiencies in the BCA and NatHERS rating tool and concluded that they do not account for the diversity of socio-cultural understandings, the inhabitants' expectations and their behaviours. This supports the studies focus of analysing a wider scope of variables.

Energy consumption by Australian households is a direct contributor to national GHG emissions. In 2007, Australia's residential sector accounted for approximately 9% of national GHG emissions, a 25% increase since 1990 (Australian Department of Climate Change, 2007). This increased share of GHG emissions for the sector outstripped most other sectors in absolute terms.

The majority of Australian homes are separate (detached) houses (77%), not units or semi-detached dwellings (Australian Bureau of Statistics, 2008), and the present study focused on this most common type of residence. In Australia, new
homes are required to meet the minimum building standards mandated by state/territory authorities, such as the specifications in the BCA (Australian Building Codes Board, 2005). States and territories all use the BCA but can impose additional requirements or exemptions. Sustainable housing aims to exceed minimum standards and incorporate features that allow the building to operate comfortably with minimum impact to the environment. There is no single benchmark for the “sustainability” measurement of residential houses but tools such as the NABERS (Australian Department Environment Climate Change and Water, 2010) and NatHERS (Australian Department of the Environment Water Heritage and the Arts, 2007) do offer some frameworks to compare homes. In Australia, new homes have to achieve a minimum thermal performance based energy rating. State and territory governments mandate minimum NatHERS ratings. For most of the homes in the present study this minimum would have been achieved using Deem to Satisfy provisions or an assessment using an approved NatHERS rating tool (commercially available via software programs such as BERS, FirstRate or Accurate) (Australian Department of the Environment Water Heritage and the Arts, 2007). NatHERS tools use a rating scale of 1 to 10, with 10 indicating the house should require no artificial heating or cooling assistance and hence being very/perfectly thermally efficient. Research by the University of Adelaide (Soebarto & Williamson, 1999) has already been conducted to evaluate the effectiveness of the NatHERS rating system to predict a home’s operational performance. After studying homes in Adelaide, Williamson and Soebarto recommended that NatHERS needed to be enhanced to improve the correlation between the rating and actual household heating and cooling energy consumption; these results helped to trigger updates in the tool (T. J. Williamson, O’Shea, & Menadue, 2001). The latest version of the engine on which
each HERS software tool is based, called AccuRate, seems now to be more precise (Kordjamshidi, King, & Prasad, 2005). Thermal energy performance is only one measure of the sustainability of a home, and hence the present study has tried to take into account additional inputs.

Fortunately some local energy and water studies had been completed in 2010. In the previous smaller study titled "The Ecovillage at Currumbin - a model for decentralised development" a small number of Ecovillage homes built between 2007-9 were compared with Gold Coast and state averages for energy and water use per capita (Hood et al., 2010). The study focused on determining the energy used to manage decentralised water systems, in this case rain water collection and treatment facilities. The Hood study found Ecovillage homes used 5.73 kWh/household/day of electrical energy and the metered comparison (Silva Park) homes in the same climate zone consumed an average of 19 kWh/household/day (Hood et al., 2010). Given the location and age of the homes from these studies, comparison could be made to the present study's data (see page 133).

To inform the study model and predict correlations, other studies were reviewed. Some 850 kilometres further south of the Gold Coast in Sydney, when Manfred (2004) studied energy use amongst 14 ABS statistical sub-divisions of Sydney, it was confirmed that domestic energy use correlated with the "number of occupants" as well as with "income" and "age". In relation to their study of residential energy consumption, the researchers commented that "since growth in per-capita income and the resultant consumption of goods and services represent the main stimuli for economic growth in modern economies, these results suggest that the physical requirements underpinning [energy] consumption will also steadily increase" (Manfred et al., 2004, p. 394). Hence, despite increased governmental
focus on programs and strategies to reduce GHG emissions and improve efficient use of water, other factors such as the nexus between economic growth and increased consumption of goods and services tends to encourage increased utility usage by households over time.

In relation to water consumption, Australia's urban water supply faces major challenges due to increasing demand, climate change and drought. This demand in turn places pressure on water storage capacity. In 2009, the Australian Government invested $12.9 billion in “Water for the Future”, an initiative to prepare the nation for lower water availability. Similarly, households have had water restrictions in most Australian states and territories since 2002 at times of water shortage. In 2007-08, 55 per cent of adults reported that their water consumption had decreased and 40 per cent stated that it had remained the same in the prior 12 months (Australian Bureau of Statistics, 2010a). This suggests there is ample opportunity to further reduce water consumption, which will be essential as the population continues to increase.

Surprisingly, few residential data are available on a significant scale to examine whether utility consumption efficiencies are achieved by increasing sustainable design attributes in residential housing. Australian Government data suggest the size of a house, number of occupants, and construction type significantly influence utility consumption. These associations indicate that increased house size, higher number of occupants, and separate houses are all related to higher utility use (Australian Bureau of Statistics, 2008).

In a study analysing “the role of government in energy efficiency and sustainability in buildings” in 2006, researchers reported that the south-east Queensland region, where the two study groups are located, has experienced
significant growth since the 1980s and at the time was growing by 55,000 people per annum (A. Miller, Ambrose, & Ball, 2006). They also reported that heating and cooling energy accounted for only five per cent of the total home energy consumption in Queensland, compared with 39 per cent as the Australian average, due to the more temperate climate. The study found that energy efficiency is constrained by the sub-divisional layout, suggesting that town and master planning should play a role and be held accountable for helping homes minimise energy efficiency. In terms of ventilation, modelled improvements resulted in a decrease in energy use of between 14 per cent and 41 per cent for the eight case study house designs. The study concluded that the difference in energy efficiencies between the dwellings related to the differences in the houses design and construction methods (A. Miller et al., 2006).

Examples like these studies demonstrate that improvements, at the planning, design and retrofit lifecycle housing development stages, can make a significant difference to the performance of housing. Such changes can also be rewarded financially if appropriate rating systems to inform the market exist; in 2002 a Canberra firm found that there was also a market preference for energy efficient houses and a clear increase in value for the highest rated energy efficient rating (EER) 5 Star houses (Energy Partners, 2003).

This review of research on the relationships among attitude, utility consumption and housing design revealed several gaps which helped to form the hypotheses for this study and these are detailed in the next section.

Research Questions and Hypotheses

The lack of knowledge about attitudinal and sustainable design impacts on utility consumption presented an opportunity to design a study to address related key
issues. The study was designed to measure both utility usage and attitudinal data for residential houses, to assist with identifying effective evidence-based approaches to improving sustainable design of homes and behavioural change campaigns. The research specifically examined the biophysical factors in settlement patterns and the impact of environmental attitudes in sustainable housing. That is, the research examined physical outcomes resulting in part from processes enacted by household occupants. The study variables also have the potential to address some of the barriers to sustainable development, by providing more information relevant to assessing costs and benefits for individuals, developers, and governments.

The elements of the study needed to include consumption data, attitudinal data and contrasts in design, to identify any key relationships, differences and trends. To develop achievable goals and a viable project method, major components of each element were targeted including utility consumption data (energy and water) and environmental attitudes. Two groups of houses, one considered sustainable and the other considered conventional Australian housing, were identified and studied. Both of these groups met the study criteria detailed in the following chapter.

On the basis of prior studies (Schnieders & Hermelink, 2006; Szatow, 2011), it was thought that sustainably designed residential buildings would demonstrate lower utility usage compared with the control houses.

The first question targeted was whether sustainably designed houses consumed a smaller amount of utility resources, which was formally phrased as “How do sustainably designed residential buildings compare with conventional homes in the same climate zone (in south east Queensland) in terms of operational resource consumption?”. This query prompts the hypothesis that “Sustainably
designed residential buildings will demonstrate significantly lower utility usage compared with conventional homes.”

Second, it was predicted that residents with stronger environmental consciousness (pro-environmental attitudes) would demonstrate lower utility use (Abrahamse et al., 2005; Balderjahn, 1988; Davis, Green, & Reed, 2009). Environmentally conscious occupants can be expected to report attitudes with a more ecocentric system of beliefs as opposed to an anthropocentric system of beliefs (Milfont & Duckitt, 2010); that is, such people have a greater sense of responsibility for their impact on the environment and a willingness to engage in pro-environmental behaviour.

Third, in combination, it was hypothesised that occupants with stronger environmental attitudes and living in sustainably designed houses would achieve the greater relative reduction in utility usage of the two groups. To the author’s knowledge, a study of this depth using such technology and a significant sample size of directly comparable sustainably and conventionally designed houses has not previously been undertaken.

Assumptions
Several primary assumptions need to be made to provide a scope for the study that was technically and physically achievable. First, the study assumed that the energy and water consumption were two of the largest and most measurable variables to calculate relative consumption habits and hence environmental impact. The method also assumed the data were reasonably accurate, and this was confirmed as much as possible through cross-checks of results and outlier analysis. Second, it was assumed that the attitudes of people did not change on average, for the duration of their time in the homes. This assumption is required because the survey was only conducted
once, per household, and thus was not longitudinal. Third, in terms of trying to assess occupant behaviour, the study used people’s attitudes as a proxy for the behaviours which impact utility consumption rates. Fourth, the survey assumed the pre-validated questionnaire would be representative of a person’s attitudes. Fifth, as the housing groups were in the same climate zone, it was assumed that climate did not play a significant differential impact in the water and energy consumption levels between the two groups of homes. Sixth, it is acknowledged that the group of housing that purported to be sustainable was targeted, due to the number of sustainably-focused houses within the estate and the fact that they were new constructions. These key assumptions and others that were relatively minor, are identified and discussed in the relevant sections throughout this thesis.

Summary
Research on utility use and environmental attitudes in residential building has studied some of the components measured by this study singularly, but the present study integrates them, using the same population, whilst also comparing design impacts. The next chapter describes the methods used to undertake the study and measure the variables of interest.
CHAPTER 2 - RESEARCH METHOD

The project method was developed by first defining criteria for sustainable housing, in line with the attributes of sustainable housing described in Chapter 1, and a set of conventional (control) housing. The next steps were to find participants within those categories, survey them, record the household utility data, then analyse and report the results.

Using the sites described below, the study was able to compare two distinctly different housing types but in the same climatic location. The utility data were able to be obtained from monitoring systems and utility bills using standardised instruments.

To assess the environmental attitudes of the housing occupants, a different measurement method was required. As environmental attitudes are an internal state, they were measured by directly asking the people about their attitudes. This was undertaken using a previously standardised and validated questionnaire as detailed below (EAI; Milfont & Duckitt, 2010). The study method had to allow for people with different levels of environmental attitude strength and the type of questionnaire used allowed this.

Site Selection

In order to determine the differences between sustainably designed housing and conventional housing, site criteria were developed. This ensured a group of sustainably designed housing and a comparable group could be clearly differentiated in terms of their design but not other factors. That is, the control group needed to be as similar as possible in aspects not related to the study group's sustainable design attributes. Specifically, the criteria were defined to control for factors such as
climate, type, size and age and target ideal problem conditions. The conditions were defined as:

- A Study Group of “sustainable housing” that was designed to meet sustainable design principles (see Appendix B and C) and contained sustainable housing attributes as defined by recognised authorities, such as those attributes listed in Table 1 on page 30.
- A Control Group of housing that did not exceed standard Australian building practice, which was defined as (merely) meeting the minimum Building Code of Australia requirements, or was designed without reference to The Hannover Principles of Sustainable Design or equivalent ESD principles.
- Housing built at a similar time and over a similar timeframe, in this case a six year period. To enable a fair comparison and remove time-related changes in standards and methods, all homes surveyed were built between 2005 and 2010.
- Housing that could be studied by researchers in a defined period, that is, within 12 months, and in an accessible location.
- Housing that was in the same climate zone, to remove climatic impacts on consumption levels.
- Housing of the same type i.e. detached residential houses, not units or townhouses.
- Housing that was located on similarly sized blocks of land i.e. not “acreage”.

The Ecovillage in Currumbin ("Ecovillage") was selected as the study group as it met the preferred criteria. It had been advertised as containing only sustainable housing and Ecovillage homes have to comply with some of the most prescriptive sustainable residential building requirements in Australia. The 60 hectare site contains diverse landforms and habitats. It surrounds the Currumbin Creek and a riparian vegetation corridor. Rainforest and dry sclerophyll forest including a native hoop pine plantation forest (approximately 20 acres) are also contained within the site. Approximately 80 per cent of the total original site has been left as open space,
whereas typical Australian suburban developments build on most of the
development site, leaving little space as shared community open-space (Landmatters Currumbin Valley Pty Ltd, 2007). The development and its housing is further detailed on page 77. The Ecovillage mandated housing was deemed “sustainable housing” under the definitions required for the study and became the “study group”.

A comparison estate, called the “Observatory” that matched the criteria for the control type, climate and age of the homes was identified in 2010. It was developed by one of Australia’s largest building companies, Stockland, and is referred to as the “control group” in the research, since it represented current standard building practice in Australia at the time, that is, conventional housing. The Observatory is a 300 hectare development site and 40 per cent of the development site is allocated as open space. The development and its housing is detailed further on page 90.

The sites met other criteria as well. Both were located in south-east Queensland, Australia, 100 kilometres south of Brisbane. As shown in Figure 5, the sites are located in a sub-tropical climate zone.
The study group is located in the Currumbin Valley near the Queensland-New South Wales border, 8 km south of the Observatory which is in the suburb of Reedy Creek, as shown in Figure 6.

Figure 6 – Locations of the two housing development sites

Source: (GoogleMaps, 2011)
Both the Ecovillage and Observatory are less than 7 km from the beach (Coral Sea and South Pacific Ocean). Summer maximum temperatures average 26°C, with a historical maximum of 38°C on record. Winter minimum temperatures average 8°C and can reach 0°C (Bureau of Meteorology, 2011b). The homes within each community were single detached houses, of a similar size and age. This, combined with their similar location, enabled a higher quality comparison.

Figure 7 and Figure 8 below show aerial photographs of the Observatory and Ecovillage developments respectively, from images recorded in 2009. The locations of these estates are similar, with the conventional estate being closer to the centre of the Gold Coast and hence, slightly closer to major facilities. For Observatory residents the bus and rail network is closer, but it is slightly further away from the Gold Coast Airport. In terms of house spacing, the housing density is greater in the control group.

Many of the homes in the control group were custom built and engaged architects. No single home looks similar to another in the study group, whereas there were similarities found in the control group. Details and comparisons from the survey data is available on page 100.
Both settings can be considered "greenfield" sites since they both developed old farmland which had no previous residential buildings on it. Minor exceptions within the study group were that the old farm home and old dairy and barn buildings were mostly reused and converted into commercial and community spaces.
House Selection Criteria

To ensure fair comparison, only potential participants who had lived in their homes for one year or more were deemed as eligible, to ensure no one-off impacts affected the utility consumption data. These points were checked prior to surveying. Those moving into a new home typically need time to get used to their home and hence it is possible that the first six months of data might not be representative of the occupants’ average utility use. Similarly, if homes less than a few months old had been included in the study, many of the participants would have moved in straight after the house had been constructed which could have meant that energy consumption associated with the final/commissioning stages of construction could have been included in billing data, unfairly weighting the results. The criteria are summarised in Table 2.

Searches to find all homes in the areas eligible for inclusion in the study were completed using satellite data from GoogleEarth (Google Earth, 2010) and a property database called RPData (RP Data Pty Ltd, 2011). Blocks of land without homes on them were excluded from the mailed out paper hard-copy invitations to participate.

Table 2 – House Selection Criteria

<table>
<thead>
<tr>
<th>Criteria (all required, for a house to be eligible)</th>
</tr>
</thead>
<tbody>
<tr>
<td>House in defined Study Group or Control Group boundary (estates)</td>
</tr>
<tr>
<td>House already built on block of land</td>
</tr>
<tr>
<td>Detached single dwelling house</td>
</tr>
<tr>
<td>New house – that is, less than 6 years old (Age)</td>
</tr>
<tr>
<td>House lived in for more than 6 months.</td>
</tr>
</tbody>
</table>
Recruitment and Participation

Recruitment of participants in the study took place after ethics approval was obtained from the University of Sydney Human Research Ethics Committee. Each eligible household was mailed an introductory letter inviting residents to participate in the study – see “APPENDIX D – Letter to Participants”. No door-knocking or unsolicited telephone calls were made to seek participants; households needed to contact the researchers to indicate that an eligible occupant was interested in participating. One adult from each study was able to nominate for inclusion. All eligible candidates/homes were included in the study. As a token of appreciation for the time and effort involved in participating, each household who participated received a $50 supermarket voucher, as identified in the ethics submission.

Potential participants were asked to mail an acceptance page, or telephone or email a researcher, to express availability. Householders did not receive any contact during the study period if members did not respond to the invitation letter. Participation was optional.

Procedures

Data were collected between 5 February and 9 April 2011. Trained research assistants visited the homes of people who opted to participate, at a mutually convenient appointment time. Data were collected in a single session that lasted approximately 40-60 minutes. After providing written informed consent, residents completed “paper and pencil” surveys. While participants completed these surveys, the research assistant recorded data from the utility bills provided. Detailed billing data such as days of electricity use, amount (kWh), and cost were recorded, so any anomalies in data recording could be identified through cross-checks, post data collection. An online version of the survey questions was created for those
participants who could not meet a university representative in person, but only three participants chose this option. Data from the study group monitoring systems were retrieved by a request to the database administrator with access permission attached on 11 April 2011 for all previous available periods (which went back to 2006 for some houses).

Water and power usage can be obtained by bills or building management systems where installed. Some bill information can be slightly misleading over shorter periods due to retailer meter reading averaging but these effects are substantially reduced when taken over a longer period, e.g., 12 months or greater, which was achievable.

Variables and Measures

To meet the study requirements the research design needed to measure utility consumption and behaviours. The design consequently included measures to capture and evaluate representative variables, and demographic parameters to enable closer analysis.

To assess the technical (sustainably design) and non-technical (behavioural) aspects of influences on utility consumption, two types of data were collected. First, key utility consumption data (including water, gas and electricity) were measured using real time monitoring systems embedded in most of the 35 sustainably designed homes within the study group. Second, data on occupants’ attitudes towards environmental conservation and resource usage were collected, to test the proposition that strong values favouring environmental conservation impacts on behaviour and therefore resource usage.
The variables included in the study are defined in Figure 3 below and following this, the measurement methods for the variables are described in detail in three separate sections.
### Table 3 – Variable definitions

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable: Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent Variables (Inputs)</strong></td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td></td>
</tr>
<tr>
<td><strong>Housing Design:</strong></td>
<td></td>
</tr>
<tr>
<td>• 0: Houses from the <em>control group</em> subdivision in Reedy Creek Queensland with post code 4227 without a sustainable design focus.</td>
<td></td>
</tr>
<tr>
<td>• 1: Houses from the <em>study group</em> subdivision in the Currumbin Valley Queensland with post code 4223 which had to comply with the comprehensive sustainability focused Architectural and Landscaping Codes, which claim to ensure more sustainable outcomes.</td>
<td></td>
</tr>
<tr>
<td><strong>Occupant (Behavioural)</strong></td>
<td></td>
</tr>
<tr>
<td>A. <em>Preservation</em> (EA): Attitude towards conservation and protection of the environment.</td>
<td></td>
</tr>
<tr>
<td>B. <em>Utilisation</em> (EA): Attitude towards anthropocentric utilisation of natural resources.</td>
<td></td>
</tr>
<tr>
<td><strong>Demographic</strong></td>
<td></td>
</tr>
<tr>
<td>A. <em>Number of occupants</em>: Number of occupants sleeping at the house on average.</td>
<td></td>
</tr>
<tr>
<td>B. <em>Other demographics</em>: Additional demographic data, detailed below.</td>
<td></td>
</tr>
<tr>
<td><strong>Indicators/Dependent Variables (Outputs)</strong></td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td></td>
</tr>
<tr>
<td><strong>Utility Consumption</strong>: average results for all data obtainable during the study period:</td>
<td></td>
</tr>
<tr>
<td>• <em>Energy</em>: Average amount of power consumed per household per day, in kilowatt hours (kWh).</td>
<td></td>
</tr>
<tr>
<td>• <em>Water</em>: Average amount of water consumed per household per day, in Litres (L).</td>
<td></td>
</tr>
</tbody>
</table>
The dependent measure, total utility use is influenced by two human manipulable factors. The first factor is “passive” sustainable design of the house, that is, whether the house has inbuilt features that allow it to be comfortable all year round without occupant intervention. Passive factors are built into the house and cannot be adjusted by occupants. Examples of such factors are thermal mass, eaves at the right length to keep the summer sun out but permit winter sun penetration and fans instead of air conditioning. To rate the passive design and sustainability features of a home that make it possible to operate more cheaply (in terms of water and energy costs), Building Code of Australia (BCA) mandated building performance ratings can be used. Designers have the option of using Deem-To-Satisfy (DTS) provisions or a performance tool (from the NatHERS range of commercial tools, namely: Building Energy Rating Scheme (BERS), FirstRate or Accurate) (Australian Department of Climate Change and Energy Efficiency, 2011). Standard buildings typically only meet the minimum requirements (currently 5 Stars or equivalent). Designers who actively include passive design techniques to allow the building to use less operational energy and water over time typically aim for 6 – 9 star ratings using a NatHERS tool. Consequentially, for this study, the “housing design” was a variable that could be measured and used to differentiate the housing.

The second factor is the operational aspects, as provided by the behaviour of the occupants. Operational factors involve operable design mechanisms e.g., the actions of the residents to reduce power and water usage such as by turning appliances off when they are not in use or putting on more clothes before turning heaters on. As mentioned earlier when measuring attitudes, the study makes an assumption that attitudes directly impact behaviour and in essence, it is using attitudes as a proxy for behaviour. A meta-analysis of attitude-behaviour
relationships “showed a strong overall attitude-behaviour relationship”, and that this was that “the higher the attitudinal relevance, the stronger the relationship” between them (Kim & Hunter, 1993, p. 331). That is, if the subject matter relevance is high, the relationship is often stronger. For example, voting behaviour, has been shown to be strongly and consistently related to voting attitudes (Ajzen & Fishbein, 1977). However, some gaps between attitude and the following behaviour have been demonstrated in relation to energy use as reported by Newton (2011a).

If the sustainable design and/or occupants attitudes were found to impact utility consumption, then the consequences would be to provide support for programs and policies targeting such triggers; for example, provide evidence for increases in minimum performance standards, such as the energy efficiency requirements in the BCA (Section J) or National Building Energy Standard. However, if environmental attitudes correlate the most strongly with utility use and, when taking into account other factors they can still explain a large proportion of the consumption, then incentive programs seeking to change attitudes would appear be more effective.

The design of this study allowed high-quality measurement of total utility use and used data about the design of the home (through thermal energy rating tools) to assess the extent to which passive design features are associated with utility use. In addition, results from a previously validated questionnaire on environmental attitudes were expected to show whether there was a significant relationship between these attitudes and utility usage. The combination of these data through multivariate analysis was planned in order to assess the relative contributions of design and attitudes to reducing utility consumption.
Environmental stewardship to protect the environment from impacts has been well documented (Kao, 2007). It has also been suggested that environmental impact (EI) is a function of population, consumption aspirations and habits, the state of technology and people's attitudes (Wadley, 2010). The present study focused on measuring the technology which is measured through the housing design in the built environment context. Then to measure people's attitudes, in a residential environment, the study design leveraged a pre-validated survey.

Environmental attitudes and/or the passive design of a home could have effects that either increase or decrease utility consumption levels. It is possible to calculate the effects of each variable and then use this empirical knowledge to improve policy and incentive schemes in a more informed approach than merely anecdotal estimates. In this study the person's actions were not directly measured. As shown in the literature summarised in Chapter 1, people's environmental attitudes tend to correlate with environmentally friendly behaviours. It is acknowledged that it is difficult to accurately measure the range of relevant occupant behaviours, especially over the full length of the study period.

Demographic and Housing Variable Measurement

In relation to demographic variables, the data listed below were requested from participants, with the questionnaire being the sole instrument. The majority chose to answer all questions. See APPENDIX E – Questionnaire for a copy of the survey. Most of the variables and their definitions were extracted and aligned to be consistent with the Australian Bureau of Statistics (Trewin, 2006) or the NABERS Home rating system developed by the Australian Federal Government (Australian Department of the Environment Water Heritage and the Arts, 2007). All of the demographic data were recorded via written questionnaires and contained:
• Address
• Months lived at this address
• House Build (completion) Date
• Number of occupants sleeping in the house on average
• Occupant Hours (Total hours that the house was usually occupied by at least one person, from 7am to midnight, on average per week). This metric was used to match the definition used by the National Australian Built Environment Rating System (NABERS) (Australian Department of the Environment Water Heritage and the Arts, 2007).
• How many weeks homes were unoccupied during the year to help determine the percent of time homes were in use.
• Size of home (total rated internal floor area) in m². Total floor area of the habitable part of the house as measured to internal faces of external walls of each separate storey of the house. Areas of unheated or inhabitable spaces such as integral or attached garages, separate conservatories, and garden rooms were not included.
• Total area of house site (lot/block) in m²
• Number of swimming pools in use and their size (litres)
• Number of bedrooms
• Number of bathrooms
• Ages of occupants (using ABS age bands)
• Genders of occupants
• Occupation of each adult
• The number of years the adults had lived within Australia
• Country of birth (Australian or overseas born)
• Highest level of schooling completed by each occupant (by ABS Category)
• Estimated weekly total household income (gross)
• Energy rating of house (Design), NatHERS rating if known and tool used. Home office size (if part of the house)
• Ownership type (owner or renter)
• House structure type
• Primary or secondary home
• Age of the house.

Many of the demographic values were used to interpret or weight the occupant interactions with the home. Respondents listed the average number of occupants within the house (per night) and the total hours per day spent in the house. This enabled data comparison of the house usage and could permit weightings if required. The demographic data also enabled fairer comparison, by excluding periods (weeks)
of non-use, if people were away from their home for extended periods. The other demographic data allowed similar pattern analysis, to check for other influences, for example occupant education, age, gender, country of origin and ownership type.

Data on the age of the house were collected to ensure all homes could be compared equitably, that is, each was less than six years old, to ensure very old homes were not unfairly compared with new homes.

**Occupant Values, Behaviour and Environmental Attitude Measurement**

Occupant representatives completed a questionnaire to evaluate their environmental attitudes. The previously validated 120 item Environmental Attitudes Inventory (EAI; Milfont & Duckitt, 2010) was shortened to 36 items for the present study. Other short forms of the inventory have been verified as satisfactory measures, as found in Study 3 of the environmental attitudes inventory (EAI) tests conducted and analysed by Milfont and Duckitt. They reported for a 72 item version that the alpha coefficients and mean inter-item correlations for the EAI short-form were highly satisfactory (Milfont & Duckitt, 2010, p. 87). Milfont also states for research focused on specific EA facets, briefer versions can be created, as discussed as part of the wider research project (Upadhyay & Hyde, 2011). For example, Milfont and Duckitt developed a 24 item version, by selecting those factors with higher corrected mean-item total correlations, yielding 14 balanced Preservation items and 10 balanced Utilization items (Milfont & Duckitt, 2010, p. 88).

The original scale has 10 items for each of 12 factors that group into two higher-order factors, namely Preservation” and “Utilisation. Only the two higher-order factors were examined in the present study. Three items from each lower order factor were selected, based on the method used by Milfont and Duckitt. They
selected the factors with the highest proven loadings, which gave a total of 21 items for Preservation and 15 items for Utilisation.

A Preservation attitude includes enjoyment of nature, support for interventionist conservation policies, environmental movement activism, sense of environmental threat, personal conservation behaviour, ecocentric concern, and support for population growth policies. A Utilisation attitude includes conservation motivated by anthropocentric concern, confidence in science and technology, support for altering nature, support for human dominance over nature, and support for human utilisation of nature. Items are answered on a seven point Likert scale, from 1 = “strongly disagree” to 7 = “strongly agree”. The scale authors reported Cronbach’s alphas of 0.95 and 0.91 for Preservation and Utilisation respectively, using the 120 item scale. These two factors also correlated strongly, $r = -0.66$ (Milfont & Duckitt, 2010). The scale authors have also examined a shorter 72 item version and found it also to provide psychometrically sound data, such as Cronbach’s alpha of 0.94 and 0.91 for Preservation and Utilisation respectively (Milfont & Duckitt, 2010). Test-retest reliability over an eight-week interval has been reported as 0.95 and 0.92 respectively for the 72 item EAI regarding Preservation and Utilisation.

The EAI has been validated cross-culturally, shows little effect of social desirability bias, and has been shown to correlate in predicted directions with other environmental attitude indicators (Milfont & Duckitt, 2010). In the present study, Preservation had a Cronbach’s alpha of 0.86 and Utilisation had an alpha of 0.73 meaning that both variables showed good internal reliability. Attitudes towards Preservation and Utilisation typically have an inverse relationship and this is the
case within this dataset, with those having low Preservation scores also having high Utilisation scores.

**Utility Consumption Measurement**

To measure operational impacts, the focus of the study was the major utilities of energy and water. “Energy” included all electricity (used and generated) and gas from permanent supplies (in this case reticulated LPG at all study group homes). It is acknowledged that gas data were not able to be collected from small gas bottles used for barbecuing/cooking used by a small number of homes. Water included all metered potable, rain or recycled water used by the occupants in the home, pools and the block/gardens.

Water and power consumption data were obtained from bills or building management systems, where installed. Most study group data were available from a real time Information Metering and Control System (IMCS) database that consolidated all readings for the majority of study group homes. Daily data from the IMCS were consolidated to obtain averages. This process involved taking the individual daily spreadsheets and converting them into monthly data, then computing one consolidated total, per utility variable, per house. For study group homes, recycling and tank (rain) water consumption readings were combined to give a total water consumption reading.

For those homes without operating IMCS systems (all control group homes and 13 of the study group homes), utility bill data were used from paper bills provided by the residents. Bill data were transposed to similar spreadsheets, with the days per billing period also recorded to enable averaging. Missing bill data were excluded from calculations. All data were then placed into one master spreadsheet for all homes, regardless of source. Random audits were conducted to ensure the
original data had been transposed correctly and study group bill data were compared to IMCS data as a second cross reference quality check. The demographic data were added to the master utility data set taken from the first section of every survey, and imported into the Statistical Package for the Social Sciences (SPSS, version 19) for more detailed analysis.

Electricity and gas data were converted into the same units to allow direct comparison and averaging. For this purpose, gas readings were converted from mega joules (Mj) to equivalent kilowatts (kW) to give a total energy value per house for a particular number of days. It was assumed that 1 kWh is equivalent to 3.6 Mj of (LPG gas) energy (Australian Department of Climate Change and Energy Efficiency, 2010) and that the household utility meters were not faulty. For this study, home energy use was defined as all gas and electrical energy. It excluded other forms such as transportation to and from the house.

**Housing Design: Study and Control Group Attributes**

This section describes the study and control group characteristics to highlight their differences and similarities. Table 4 lists a summary for direct comparison of the key differences.
Table 4 – Study group and control group attribute comparison

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Study Group (sustainable housing)</th>
<th>Control Group (conventional housing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed site building Code</td>
<td>Yes - Architectural and Landscaping Codes (Covenant)</td>
<td>No</td>
</tr>
<tr>
<td>Recycled building materials</td>
<td>100% of homes</td>
<td>No active or encouraged use</td>
</tr>
<tr>
<td>Community facilities</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>House northern orientation focus</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Block (Lot) designed to north</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Internal thermal mass</td>
<td>Mandated</td>
<td>Not actively encouraged</td>
</tr>
<tr>
<td>Air conditioning (cooling)</td>
<td>Not permitted by Codes</td>
<td>All homes by choice</td>
</tr>
<tr>
<td>Solar energy generation</td>
<td>100% of homes</td>
<td>8% homes</td>
</tr>
<tr>
<td>Internal home utility monitoring system</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Solar hot water with gas backup</td>
<td>Mandated</td>
<td>Minimal use</td>
</tr>
<tr>
<td>Broadband services</td>
<td>Various providers</td>
<td>One provider</td>
</tr>
<tr>
<td>Reticulated gas supply</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Local food production</td>
<td>Often</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Cats or Dogs permitted</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Pre-approved home office space</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Swimming pools</td>
<td>One shared pool</td>
<td>50% of homes have pools/spas</td>
</tr>
<tr>
<td>Open/shared space as a percentage of private lots</td>
<td>80%</td>
<td>40%</td>
</tr>
<tr>
<td>Awards for sustainable/residential/community design</td>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>
Sustainable Design: the Study Group Housing and Environment

The Ecovillage (study group) is a developer-led community which, when complete in 2014, will comprise 147 home sites and six commercial lots. Private buyers purchased the sites (lots) and built their own private homes on them which are all part of a Community Title scheme to support shared ownership of common facilities and land for farming and recreation.

By late 2010, over 60 homes had been completed, enabling a sizeable study (for a sustainable housing population) and in addition, many residents stated they were open to participating in such research. In addition, internal real time monitoring systems had been installed in most homes, as mandated by the Ecovillage Architecture and Landscape Codes. Data from the monitoring systems permitted detailed analysis and higher quality inference than is typically available from utility billing data.

A principal body corporate manages all major common areas and beneath it subsidiary bodies corporate manage the three (staged) residential areas and a small set of commercial lots. The development applies the Body Corporate and Community Management Act of Queensland. The Community Management Statement features by-laws and regulations in accordance with ecological and community values. Land rates are reduced by community title ownership of shared land areas. There are no restrictions on when owners can buy or sell their individual lots. The Body Corporate fees include costs for administration, maintenance and recycled water treatment. Residents capture their own rain water in water tanks, thereby avoiding Council water rates. Reticulated gas (LPG) and broadband internet services are available for each home parcel.
Home parcels range from 500m² to 10,000m² with the majority being approximately 1,000m². The overall estate comprises 17 one bedroom home lots, 26 two bedroom home lots and 101 three bedroom plus (unrestricted) lots over a total of 272 acres. A small quantity of blocks were targeted towards first home buyers. Prices for the land started at AUD$175,000 in 2005 for small lots and up to $595,000 (in 2012) for larger lots. The lots (house blocks) in the Ecovillage were extensively planned and documented to ensure designers took advantage of the intentional orientation and location of them, their solar access and met the detailed building code requirements – see Figure 9. For example, ideal positions were identified for vegetable gardens, tree protection zones and shared greenways (common areas between each 6-20 lots within the development controlled at a subsidiary body corporate level).

Figure 9 – Sample of a detailed lot evaluation for a study group house block

Source: Landmatters Currumbin Valley Pty Ltd (2007)
The sustainable housing was developed using specific design codes which assisted *The Ecovillage atCurrumbin* to win the Federation Internationale des Administrateurs de Bien-Conseils et Agents Immobiliers (The International Real Estate Federation) Prix d’Excellence Award in 2008 and 30 other national awards (The Fifth Estate, 2009). The Ecovillage has seen a high concentration of award winning sustainable independent homes been built in recent years.

The developer used several principles to achieve a desired project outcome that (a) is sustainable over time; (b) relates to the local and global environments; and (c) provides and allows for future beneficial change to occur in design, infrastructure and regulatory mechanisms (Landmatters Currumbin Valley Pty Ltd, 2005). Many of the guiding principles within these concepts were taken from or incorporated existing government controls and rating systems, including the NatHERS star rating system for predicted thermal comfort performance of housing designs. The Guiding Principles (Landmatters Currumbin Valley Pty Ltd, 2005) are summarised in “APPENDIX C - Summary of Ecovillage Guiding Principles”.

A unique planning approval condition was negotiated by the developer and local council and used to limit the density (amount of development) on the site. This condition includes limiting the number of bedrooms per lot, which has the effect of reducing the size of buildings, and hence number of people in the area, which was traditionally a farming and acreage dominated region, as per Table 5 (Landmatters Currumbin Valley Pty Ltd, 2007) which lists the first two stage Gross Floor Area (GFA) limits as an example.

This condition was applied because reducing lot sizes would not have necessarily reduced house sizes, increasing the infrastructure required to support the
development in the area, including but not limited to road upgrades and maintenance, waste removal, water and power.

Figure 10 - Image of an energy efficient house within the study group

Figure 10 pictures an example of a house from the study group, including its rain water tanks, long eaves to the north, low-emissivity glazing and recycled material use. This particular house won a local Housing Institute of Australia energy efficiency award. The recycled materials included old tram tracks for steel I-beams, floorboards from an old barn, local rocks for retaining walls and reconditioned internal timber doors.
Figure 11 shows an internal view of a study group house, that includes task specific lighting, multiple lighting options, a suspended polished concrete floor (to provide internal thermal mass) and low VOC finishes.

Residents in the study group reported verbally that they believed their homes took on average 10 per cent to 40 per cent longer to complete compared with conventional building times, a point which should be considered when evaluating the economic sustainability of such an estate. Kit homes have not been used at this site, as these designers and builders have found it too difficult to customise their homes to make them comply with the Ecovillage specific building codes. One prefabricated home is now built in the estate.

Community facilities include a community hall, pizza oven, outdoor pool, games room, barbeque facilities, gymnasium, meeting room, showers, toilets, picnic
facilities, community kitchen, library, Balinese-style huts and children’s playground. Some existing buildings were used to create these facilities, reducing the overall embodied energy and resource impacts of the estate. A community meeting or event is usually held in the Community Hall at least twice a week, with events such as Yoga, Pilates, movie nights and dancing being regular options for locals. Annual balls, dinners, weddings, birthdays and other celebrations are also conducted in the hall at little or no hire cost to residents. A recycling depot is also planned for the collection of used products and goods, for reuse or recycling, before any final disposal is considered. Residents often share resources and labour, for example childcare, trailers, utes and garden produce.

The original “Queenslander” style farmhouse at the entrance to the site was converted into an interpretive (education) centre and then a cafe. This building also includes five commercial offices in the new upper level. The Village Centre precinct includes six courtyard (duplex) 1-2 bedroom home parcels. There are plans to build six Home Studios with apartment living above and resident-used commercial shop space below. Construction of a bakery, convenience store and small school is also planned. Several residents run small businesses from home, such as architects, massage therapists, and landscape designers. Apart from the local cafe, the nearest local shops are a distance of 5.4 km and there is a major shopping centre 8.7 km away by road.

The study group’s roads are smaller than usual and most contain no hard guttering. This provision allows rain to flow into the permeable surrounds, rather than creating volumes of storm water that need to be managed with large stormwater pipes (Landmatters Currumbin Valley Pty Ltd, 2006). Swale drains collect water in storms and distribute the water along streams and ponds which slows the water and
provides breeding grounds for frogs, birds and other wildlife. The roads typically curve around a set of 6-9 homes, forming an eco-hamlet. In the middle of each eco-hamlet are typically soft open greenways designed to allow children to play in safety, viewed from the living areas/kitchens of surrounding homes. Traffic speed limits on the study group’s land are reduced for safety, noise reduction, and amenity reasons, often to 25 km/hour. Most eco-hamlets contain bicycle and pedestrian friendly laneways. Local aboriginal language names were used for each precinct (Ecohamlet) and were contributed by representatives of the local Kombumerri people. For example, the Yagoi Place eco-hamlet is named after the bandicoot, a small Australian native mammal.

Streets are planted with local endemic plant species. The planting of edible species is encouraged and most residents grow at least some of their own food in vegetable gardens and own chickens for egg production. Larger orchards and farming are also planned. Pesticides are only used in extreme cases to avoid any affecting waterways, ponds and nearby ocean water quality. No dogs or cats are permitted by the Gold Coast City Council covenant on the land. As a result, the site is home to numerous native animals including over 60 kangaroos, 163 bird species and occasionally echidnas. Efforts were made to protect all vulnerable flora and fauna with the lots designed around any sensitive areas.

In relation to transport, most families own one or more cars. Some residents in the study group estate have reduced the number of vehicles they own since moving to the estate. There are no public bus services in the local area and the nearest is 3km from the site. The Gold Coast train services starts at Varsity Lakes, some 15km by road, and travels north to Brisbane City and the Brisbane Airport. The Gold Coast airport is 15km from the study group estate by road.
The community operates its own website and private internet-accessible portal, which residents can join to be notified of events or discuss issues, see www.villagehub.com.au. Fibre optic cable is installed throughout the estate to provide alternative internet and phone services. Further information about the site is available on two websites managed by the developer: www.theecovillage.com.au and www.sustainablegreen.com.au.

Table 5 – Gross floor area (GFA) limitations on study group lots

<table>
<thead>
<tr>
<th>Quantity of Lots with GFA limits</th>
<th>No. of Bedrooms</th>
<th>Maximum GFA per residence (m²)</th>
<th>Maximum GFA for out buildings (m²)</th>
<th>Total GFA (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Lots</td>
<td>1</td>
<td>140</td>
<td>100</td>
<td>240</td>
</tr>
<tr>
<td>9 Lots</td>
<td>2</td>
<td>180</td>
<td>100</td>
<td>280</td>
</tr>
<tr>
<td>43 Lots</td>
<td>3</td>
<td>220</td>
<td>150</td>
<td>370</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>250</td>
<td>150</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>280</td>
<td>150</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>310</td>
<td>150</td>
<td>460</td>
</tr>
</tbody>
</table>

The developer was able to convince the local electricity network provider to use smaller estimates for energy demand than from standard modelling, and hence infrastructure connections, because each home was required to be energy efficient, prioritise gas appliances and generate its own solar power on site, limiting the need for a large incoming connection to the main electricity grid.

All buildings within the study group’s subdivision must comply with regulations of the local Gold Coast City Council and National Building Code of Australia. In addition, study group buildings must comply with Architectural and Landscaping Codes (ALC) created by the developer as the local covenant.
The codes are more than 70 pages long and incorporate goals, recommendations and minimum standards. An explanatory section is provided prior to each requirement, to assist owners and designers to understand the reasoning behind the conditions. Many of the codes are prescriptive in nature rather than performance based.

The codes for the Ecovillage banned air conditioning (despite the development being located in a sub-tropical climate region) and promoted solar passive design techniques, making this housing theoretically much more sustainable compared with conventional home designs.

A Village Design Panel administers the code approval process and assists with designs on request. It ensures residents comply with the local Codes or can demonstrate that their actions are equivalent. The Codes which go beyond the national and Council requirements are summarised in categories below:

**Water**

Houses in the study group all collect and use rainwater from roofs for household use. All grey and black water is taken from each site and treated at the Waste Water Treatment Plant. Once treated to Class A+ standard, the water is pumped to holding tanks on the top of a hill. From there, it provides all stage 1 and 2 homes with recycled water for irrigation use and all toilet flushing. It can be used for above surface irrigation but is not treated to potable water standard. Residents have set washing product standards (for soaps and cleaning fluids etc) to ensure that toxic chemicals to not enter the system, which could hamper the first phase of the naturally aerobic wastewater breakdown process. The system is uses a low-pressure membrane filtration system with pads that contain live bacteria. Storage ponds and
tanks help to improve the water. Final processing involves an ultraviolet filter and a small dose of chlorine before the water is stored in tanks.

Energy

The electricity network is connected to the state’s electricity grid via underground lines. Home owners are required to generate some of their own power via photovoltaic panels, typically installed on roofs; all homes are required to have a minimum of 1kW of capacity which, in the location (28\(^\circ\) latitude) should generate 5kWh of power per day on average. Installation of a solar hot water system is required. The codes encourage the use and purchase of only appliances that are highly energy and water efficient. Electric clothes dryers are discouraged and rare. Air conditioning is prohibited, since it is not deemed necessary due to the passive design of the homes which is expected to keep them cooler in summer and warmer in winter, than conventional designs. Energy efficient lighting is mandated and a night time Dark Sky Policy ensures lighting energy and light pollution are minimised.

Metering

An information metering and control system (IMCS) is mandated by the codes. In 2011, the only approved system that had been used to provide this functionality was a system called EcoVision. It was available in three options: Standard, Intermediate and Advanced (EcoVision Solutions, 2009). The standard variant is used by most homes and provides information to the occupants on all:

- solar PV generated
- lighting energy
- water pumping energy
- general power outlet energy
• tank water used
• recycled water used
• gas used
• recycled water shut off control.

The intermediate system option includes the following in addition to the standard functions:

• rainwater tank level
• temperature and humidity for two different areas in the house
• ambient weather conditions including temperature, rainfall, humidity and wind speed.

The advanced system adds control and includes:

• occupancy detection and security system with mode selection, event handling and alarm and an external messaging facility
• potable water pressure reduction solenoid valve (for automatic savings on water upon low tank level)
• log of lighting and power events
• lighting and general power outlets (to eliminate standby power usage)
• fire warning system.

The system gathers data from sensors placed around the house (for example, electricity meter box, water tanks, gas meter, temperature sensors on walls) which provide readings in real time (every six seconds) back to a small touch screen personal computer in the house. These data are then transmitted to a central server in larger packets. The user interface displays summarised data that are easier for residents to interpret. Occupants merely touch the screen to turn the display on. The upfront capital cost to the owner ranges from $3,410 to $12,000 plus installation, depending on the system level. The ongoing operational cost is the electricity required to power the unit continuously. The raw data are transmitted using a
separate port along the fibre optic network, to a main computer server where all data can be extracted and analysed for trends or used to support research such as this study.

*Materials*

The study group’s Codes require that some recycled materials are included within each building. Typically this condition is met through the use of recycled timber (floorboards), steel and thermal mass (such as bricks or besser blocks).

*Waste*

There is no local individual rubbish collection and residents are encouraged to recycle what they can on their own block, before using the paper, glass and plastic recycling and general waste bins at one corner of the site. Residents are encouraged to reduce, reuse and recycle all waste on site and specialist facilities are being developed to facilitate this approach.

*Home Offices and working from home encouraged*

Under the Community Management Statement, space of up to 50 square metres is pre-approved and automatically permitted for commercial use (as a “home office”) for each house.

*Thermal Performance*

All study group buildings must contain some thermal mass in an attempt to help control the temperatures inside the houses. This outcome is often achieved using internal brick walls or suspended concrete slabs. Some owners have also used mud-brick walls and strawbale construction to improve the thermal efficiency of the spaces.
Fences

Other than natural reeds to screen washing lines, fences are prohibited. This provision tends to improve the visual security of the area and encourages community interaction and the sharing of spaces and their maintenance. Lawns are minimised and make way for native plant species or food producing species.

Energy Rating

In 2005, Queensland homes were required to achieve a 5 star energy rating using a recognised NatHERS rating tool, and homes within the ecovillage were further required to meet the specific study group Codes. The BCA energy rating benchmark has now increased to 6 Stars as per the Queensland State minimum introduced in May 2010. Some homes in the Ecovillage used the Deem to Satisfy provisions to pass this requirement and several also calculated ratings using NatHERS approved software.

Restrictions on Sale of Undeveloped Lots

To prevent people from trying to profiteer from land value increases alone, first time lot owners are prohibited by anti-speculation clauses from selling their lots before they have built an approved home on them. Buyers are also briefed on the specifics of the development process and codes before purchasing. Purchasers have therefore tended to be people interested in a more community focused mode, sharing resources, enhancing the biodiversity on the site and sustainability in general, rather than those who own cats or dogs, or wish to live an independent lifestyle.
**Summary**

The above summary of the development codes are only a snapshot of the extensive ESD requirements and other finer guidance/conditions are included in the full document provided to all lot buyers.

In conclusion, the study group provided an unmatched sample of homes and residents focused on trying to achieve sustainable outcomes without compromising their quality of life. It will be interesting to see how the homes stand the test of time and if any utility savings can be maintained; and similarly if the complex governance structure supports the decision making processes sought by residents once all residents are living in the community.

*Conventional Design: the Control Group Housing and Environment*

The conventional estate was intentionally selected for its location and ability to be compared. It contained conventional contemporary Australia housing as described further below. The site of 300 hectares was developed by the Australian company Stockland and was subdivided into 880 home parcels with the first home finished in 2005. At April 2011, approximately 600 blocks had been sold, and of them 428 had a finished house constructed on them, with some later stages still awaiting release to the market (Holbrook, 2011).

The blocks typically range from 732m² to 1,368m² with the average size of the lots studied being 770m². Land prices have ranged from AUD$290,000 to $780,000 (Holbrook, 2011). The layout is typical of a modern Australian suburb, with the roads serving as many lots as possible and being a prominent feature, but 40 per cent of the development site is open space which is significant. In most locations two lane roads are standard and there are significant steep hills in some areas. An old quarry is located to the south of the site. The developer aimed to maximise the
economic return of the site, within the constraints of the topography (Confidential Contact (Local Planner), 2011). The area has many steep hills and water courses which were impossible to create lots on. Several became open space reserves between homes (Confidential Contact (Local Planner), 2011). It was recognised as a prime site for development in the area, given its proximity to the beach, hills, Gold Coast, airports and Brisbane. The site is home to the protected glossy black cockatoo (the most threatened of Australia’s cockatoos) and efforts were made to protect its habitat. The estate was targeted towards second and third home buyers, as the land in the area is relatively expensive when over a quarter acre in size. The land was previously used by cattle graziers and, prior to them, by local aboriginal tribes.

The nearest local shops are a distance of 3.7km by road and The Treetops (a major) shopping centre is 6.6km. The Gold Coast airport is 22km by road and Brisbane is 85km. Local bus and train services are available from Varsity Lakes train station four kilometres by road from the site. It is a ten minute drive to a large local football stadium. The estate provides some shared barbeques and seats and 15km of walking trails.

The inclusion of domiciliary separate spaces for adults and children, pools, spas, entertaining areas and suburban gardens and streetscapes are common. Some homes have attempted to provide shared sporting facilities to local areas, for example basketball rings along roads, suggesting an unfulfilled demand for such functions – see Figure 12; this house features black metal roofs, grass and significant external thermal mass.
Figure 12 – Example 1 of Control Group housing

Figure 13 – Example 2 of Control Group housing
Figure 13 shows another typical control group house, with fencing, dark roof, steel and brick, grass, a grey/black/white dominated colour scheme and significant fencing, which is not prevalent in the study group.

The estate has been cabled to support Telstra Smart Communities connections and residents must connect to the Telstra underground fibre optic based network to obtain internet services. Further information about this development is available at the developer’s website www.stockland.com.au.

Owners building within the control group estate have to comply with regulations via a covenant titled the The Observatory Design Essentials which is four pages in length. It controls some basic design components such as fencing, colour use, roof types and glazing. There are no guidelines or resources specifically to encourage “environmentally friendly” housing or “sustainable” material use (Stockland, 2010) and the estate would appear to be relying on the Building Code of Australia to deliver the minimum standard/expectation. On the Stockland website there is a short description of the Telstra communication infrastructure and “living with nature”, under the heading of Sustainability (Stockland, 2011).

The majority of the features from the study group ALC covenants were not evident in the control group homes. However, a small percentage of control group homes had photovoltaic solar energy panels (8%) at the time of the study’s data collection.

Statistical Analysis Method

Data collected were placed into spreadsheets and checked before being analysed in the statistical software analysis package called Statistical Package for the Social Sciences (SPSS, version 19). An alpha level of 0.05 was used for analyses. The analyses were carried out in the following order (Ramsay, 2005):
a. Descriptive statistics were examined and data were checked for erroneous entries and for conformity to the assumptions of statistical tests.

b. The two groups were compared on all demographic, predictor and outcome variables by using t-tests. This analysis enabled testing to determine if the means of the two housing groups were significantly different for selected variables.

c. Relationships between pairs of variables were examined using Pearson correlations to test if there was a linear relationship. In addition it was possible to compare the predicted (simulated) energy consumption of the homes and their actual consumption, via a correlation. NatHERS tools can only simulate the estimated heating and cooling performance of homes, but theory suggests higher star rated homes should use less mechanical heating and cooling and hence, report lower overall power consumption levels. So if there is an inverse relationship between high NatHERS ratings and lower energy levels, then it would suggest the simulation tools are performing as expected. See the section titled Utility Consumption on page 45 for more information about on NatHERS, and Figure 19 on page 114 for the results.

d. To further understand the interrelationships among variables, the multivariate analytic technique of hierarchical multiple regression was used. Multivariate regressions permitted analysis of the relative impact of the main predictor variables while controlling for other factors, including home size and occupant levels (Manderson, 2006; Mertler & Vannatta, 2002).
e. Additional analyses were required to disaggregate environmental attitudes from sustainable design, due to the fact that, as expected, the study group reported higher pro-environmental attitudes. Two types of such analyses were conducted:

- Correlations between predictors and utility use were performed within each group separately.
- A median split was calculated for each of the environmental attitude variables and participants with attitudes above and below the median from each estate were identified. These four groups were then compared using a Group 2 (Study, Control) x Attitude 2 (High, Low) factorial ANOVA, for each of the environmental attitude variables.

The main, multivariate analyses used hierarchical multiple regression to determine what relationships sustainable design and environmental attitudes had with utility use. The regressions also included other variables to control for other factors that could affect utility use. These additional variables included size of homes and the extent to which the house was used. To summarise, if a standardised regression weight (beta) such as $\beta_1$ or $\beta_2$ is statistically significant in multiple regression, then it indicates that the variable associated with that regression weight is significantly related to utility use even when other factors have been controlled (Mertler & Vannatta, 2002). In hierarchical multiple regression, predictors are added in blocks, so that it is possible to test whether any block of predictors makes a statistically significant difference to variance accounted for in the outcome variables. The order of entry of predictors is determined in advance by the researcher on theoretical and hypothesis-testing grounds. In this study, house and demographics
were entered at the first step of the hierarchical multiple regression and the two environmental attitude variables were added at the second step, to see whether they accounted for greater variance in utility usage after other relevant variables had already been statistically accounted for (Mertler & Vannatta, 2002).

The regression equation with all predictors included can be written as:

\[ U_i = \beta_0 + \beta_1 ESD_i + \beta_2 EA_i + \beta_3 Size_i + \beta_4 Occupied_i + \beta_5 Occupants_i + \varepsilon_i \]

Where

- \( i \) is 1, ..., \( n \) and \( n \) is the number of data points (participants)
- \( U \) is Utility Usage (dependent variable)
- \( ESD \) is Ecologically Sustainably Designed (independent variable)
- \( EA \) is Environmental Attitudes (independent variable)
- \( Size \) is Size of the house (floor area)
- \( Occupied \) is % of time the house is used on average
  (of available operational hours)
- \( Occupants \) is Number of people using the house (per day) on average
- \( \beta_0 \) is the Constant
- \( \beta_x \) is a Coefficient

The t-tests and correlations will help to answer the first two research questions, namely (a) how do sustainably designed residential buildings compare with conventional homes in the same climate zone in terms of operational resource consumption, and (b) what impact do environmental attitudes have on household utility usage. The hierarchical multiple regression permits reporting on the third research question by considering the main variables together.

In conclusion, the method selected aimed to capture the required data, from clearly identified groups which contained the preferred level of sustainable design.
attributes. The study design used reliable variables frequently used in housing studies (energy and water data) and a pre-validated questionnaire. The study was enhanced by being able to keep several environmental factors constant, such as climate, house type and house age.
CHAPTER 3 - STATISTICAL RESULTS

Introduction

In order to evaluate the hypotheses and understand the actual relationships among occupant variables, sustainable housing design, and resource consumption, the data needed to be de-identified, consolidated and analysed. The previous two chapters described previous studies on the subject of interest, research questions and the method to be used for the research. This chapter’s objective is to report on the data collected and the results of the statistical analyses. It begins with response rates, data screening and then the statistical analyses. Discussion of the results is provided in chapter 4.

Response Rates

In the study group, 64 houses had been built as at January 2011. It was determined that 14 had been finished for six or fewer months, so they were excluded from the study as justified in chapter two. Three homes were empty for several months around the time of the study. A total of 33 participants were able to respond with utility data out of a possible 47 homes, giving a response rate of 70 per cent; all 35 study group occupants were able to complete the survey. Factors that are likely to have contributed to the high response rate in the study group include that one of the researchers was known to several of the residents and that residents are used to studies of the estate goals.

Of the homes in the control group, 40 participated in the survey out of a possible 428. It is estimated that 20 homes were empty during the time of the study, and if it is assumed that 70 homes had not been lived in for the minimum six months and hence did not meet the inclusion criteria, hence the response rate was estimated...
to be eight percent from all possible control group respondents. All the homes that were studied were built between 2005 and 2010.

Consumption data were not available from six of the (75) participating homes, as shown in the sample totals in Table 6.

Table 6 – Sample and population comparison

<table>
<thead>
<tr>
<th>Method</th>
<th>Study Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility consumption data</td>
<td>33</td>
<td>36</td>
<td>69</td>
</tr>
<tr>
<td>Survey questionnaires- all respondents</td>
<td>35</td>
<td>40</td>
<td>75</td>
</tr>
<tr>
<td>Total possible study population</td>
<td>47</td>
<td>428</td>
<td>475</td>
</tr>
<tr>
<td>Effective utility data response rate</td>
<td>70.2%</td>
<td>8.4%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Data Screening

The purpose of data screening is to ensure the data have been entered correctly and meet statistical assumptions required for analyses, for example by looking for out-of-range values, checking for outliers and dealing with any abnormality. Initial inspection of the utility data indicated some of the homes had experienced meter problems or abnormal usage. Data for the affected days were removed from calculations of the home’s average use if one of the following conditions applied:

- There was an obvious meter error (for example “999999”) in the database field for a particular time period.
- No reading for a particular period was given, e.g. when meters were broken.
- The home was known to have experienced usage unrelated to that house. One example was when a person shared their power with a neighbour for six weeks to complete the neighbour’s house, which gave an inaccurate representation of power use for that particular period.
Descriptive Statistics and Comparison of the Two Groups

*Household Characteristics using Demographics*

Table 7 shows the key demographic characteristics of residents in participating households.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondents (surveys with valid demographics)</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Homes with dedicated “Home Office” space</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>Age of residents (average, in years)</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Age of home (average, in years)</td>
<td>3.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Tertiary educated occupants (in the household)</td>
<td>61</td>
<td>53</td>
</tr>
</tbody>
</table>

In terms of the “age of the homes”, both means were similar at 3.5 (SD = 1.4) years for the control and 2.4 (1.1) years for the (more sustainable) study group homes. Only one participant was renting a home with the remainder being home owners. All occupants used their houses as their primary place of residence, and not as holiday or secondary homes.

The most common age bracket for residents from participating study group homes was 40-44 years of age. The largest age group in the conventional homes consisted of children aged 5-9 years. Given the age bracket responses, the average age of the study group residents was estimated to be 40 years old whereas the
conventional housing responses suggested an average age of 33 years old, indicating that the control group families were younger and had more children. In percentage terms, 25 per cent of residents were children among study group, compared with 39 per cent for the control group; this was a statistically significant difference \((Z=1.98, \ p<0.05)\).

In terms of gender, 51 per cent of the residents in the sample homes were female, which is close to the average Australian gender ratio. The gender of study participants was also reasonably balanced, with 59 per cent of the respondents being female. Taken together, these results suggesting there was no substantial gender bias in the sample. 61 per cent of residents were born in Australia, compared with the Australian average of 76 per cent \((\text{Australian Bureau of Statistics, 2006-7})\). Of the 114 adults, 74 per cent had obtained a university degree (or higher) qualification; and 60 per cent of them were from the study group. In total, the respondents from the control group homes had obtained seven masters or PhD qualifications and the (more sustainable housing) study group, eleven.

There was no statistically significant income level difference between the two samples. Only six respondents chose not to answer this question. The modal category of the 69 responses was “$1,000 to $1,499” per week which is similar to the ABS Australian average recorded figure of $1,020 per week for May 2011 \((\text{Australian Bureau of Statistics, 2011})\). Household incomes comprised all gross moneys or in-kind receipts, which were available to support consumption by the household, as a weekly average.
Household Characteristics

The number of occupants and size of house were both significantly lower in the study group than in the control group. As shown in Table 8, the average number of occupants per house was 21 per cent lower in the study group (2.7 people per night) compared to the control group (3.4). In terms of size (internal rated floor area, which excludes garages), the study group houses were significantly smaller (194 m²) than the control group houses (329 m²). The amount of time houses were “occupied” was comparable (79-80 per cent) in each community and was found not to exhibit any statistical significance between the two groups.

Houses were unoccupied for two weeks per year on average and the average internal rated floor area of all sample homes was 266 m² and this was used extensively in the multivariate analysis. The majority of the houses had three
bedrooms with the control homes having an average of 4.2 bedrooms compared with 2.7 bedrooms for the study group homes. The control homes contained 2.4 bathrooms compared with 1.8 in the study group houses.

On average, 28 per cent of all the sample houses had spa, plunge or swimming pools, but only one surveyed house in the study group had a small plunge pool. The study group community across each of the 147 lots, shares one large pool containing approximately 315,000 litres of water. However 50 per cent of houses within the control estate had one or more pools each, averaging 47,500 litres in size each and this would have contributed to the utility consumption levels recorded.

To summarise the power sources, all study group houses use reticulated gas (LPG) for specific power requirements including cooking, heating, (solar) hot water gas backup and barbeques. The control estate does not have a reticulated underground supply of gas. Eleven control houses used LPG bottled gas (in small quantities), presumably for barbecues and some gas stove cooking and these unmetered sources were not able to be included in the study. Only three houses in the control estate generated electricity via solar photovoltaic arrays, whereas 31 study group houses had such systems installed.
Table 8 - Descriptive and t-test statistics

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Control Group (0)</th>
<th>Study Group (1)</th>
<th>t-test</th>
<th>df</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kWh/household/day)</td>
<td>22.76 (9.8)</td>
<td>9.65 (3.6)</td>
<td>7.59</td>
<td>65</td>
<td>.000</td>
</tr>
<tr>
<td>Water (Litres/household/day)</td>
<td>488 (200)</td>
<td>426 (200)</td>
<td>1.10</td>
<td>46</td>
<td>.277</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>3.4 (1.3)</td>
<td>2.7 (1.1)</td>
<td>2.83</td>
<td>65</td>
<td>.006</td>
</tr>
<tr>
<td>Size of house (m²)</td>
<td>328.6 (53.4)</td>
<td>194.4 (67.2)</td>
<td>9.01</td>
<td>64</td>
<td>.000</td>
</tr>
<tr>
<td>Occupied (%)</td>
<td>80.1 (19.0)</td>
<td>79.3 (17.9)</td>
<td>-0.29</td>
<td>65</td>
<td>.771</td>
</tr>
<tr>
<td>Preservation</td>
<td>4.92 (0.62)</td>
<td>5.88 (0.59)</td>
<td>-6.44</td>
<td>65</td>
<td>.000</td>
</tr>
<tr>
<td>Utilisation</td>
<td>3.35 (0.61)</td>
<td>2.65 (0.59)</td>
<td>4.75</td>
<td>65</td>
<td>.000</td>
</tr>
</tbody>
</table>

df: degrees of freedom as determined by the sample size from each group available for each analysis.

Note: t-tests for "energy" and "occupied" used transformed variables but means and standard deviations are presented in raw score form for ease of interpretation. The square root of Energy was used to transform it, due to positive skew in Energy. A reflect and square root transformation was used for "occupied", due to negative skew. T-test values associated with probabilities of <0.05 are considered to indicate statistically significant differences between the two groups of houses. The criterion is the variable used in the specific analysis to compare the study group and control group homes.

The next section describes differences in utility consumption and attitude data. Discussion of the significant results and trends is undertaken in Chapter 4.
Utility Usage and Environmental Attitudes Results

Energy data were available from the majority of households. Water data were not available for some households, so these analyses were based on a smaller number of cases. The primary variables were inspected to check whether they met the assumptions for parametric analyses.

The average energy use was 16 kWh per household per day and the average water use for all valid data was 467 litres per household per day. In terms of gross energy consumption, the study group homes used 58 per cent less than the comparison conventional estate, and this difference was statistically significant as per Table 8. When taking into account the solar energy generated, the study group used 75 per cent less (net) energy. As discussed in the Methods section, these calculations for energy included reticulated gas, as well as electricity. The study group used an average of 10 kilowatt hours per household per day (kWh/household/day) compared with 23 kWh/household/day for the control homes and the Queensland average of 20 kWh/household/day (Queensland Government, 2011). The majority of the energy consumption analysis was completed excluding the self-generated power and significant results were still found.

In terms of greenhouse gas emissions for the operational energy used, the study group emitted 3 kg CO\textsubscript{2}-e per day (1.1 tonnes CO\textsubscript{2}-e per annum) compared with the contemporary homes in the control group that emitted 20 kg CO\textsubscript{2}-e per day (7.5 tonnes of kg CO\textsubscript{2}-e per annum) on average. This difference, when comparing GHG emissions, is greater than the raw energy consumption comparisons above due to the lower relative GHG emissions arising from LPG (gas) combustion compared to Queensland coal fire powered electricity (Australian Department of Climate Change and Energy Efficiency, 2010). Also, the study group generated 4.3 kWh/day, on
average, of its own solar electrical power, reducing the total electrical energy impact. The difference equates to a 87 per cent difference in emissions and the study group emitting seven times fewer operational energy emissions compared to the control group. The majority of the energy consumption analysis was completed excluding the self-generated power and significant results were still found.

Converting the data to per person (per capita) metrics allowed comparison with some other studies. Per capita utility data were calculated as the average utility consumption for that household divided by the number of people residing in the household. Average energy consumption was 4.04kWh/person/day (ESD = 1.56) for the study group and 7.51 kWh/person/day (ESD = 2.66) for the control group (46 per cent more than the study group occupant average).

Average water usage per home was 426 litres per household per day in the study group and this level showed no statistically significant difference to the control group homes studied (488L/household/day). There were fewer people in total in the study group homes (94) compared with the control group (137) and, when calculated, the per capita consumption rates for water in the study group (173L/person/day) once again did not differ significantly from the consumption in control group homes (156L/person/day). It is interesting to note that whilst control group homes receive water bills for their water consumption, the study group use primarily rain water so do not incur such ongoing operational costs, however, they need to fund the initial capital cost of rainwater tanks. Also, the study group homes pay body corporate levies, which include a charge to cover the cost of recycling the water and its provision back to homes for reuse for toilet flushing and irrigation.

As anticipated and shown in Table 8, pro-environmental attitudes were significantly higher among the participants from the environmentally intentional
study group than among those from the control group. Preservation scores were significantly higher and Utilisation scores significantly lower among study group than control group residents. This suggested the study group occupants were relatively more interested in preserving more and utilising fewer resources. The attitude data were put to use in the correlation and then multivariate analysis, as described below, to test the study hypotheses.

Correlations among Major Variables

Pearson correlations among the main variables in the study were analysed to identify significant relationships between pairs of variables and the results are shown in Table 9. All of the major independent variables correlated significantly with Energy consumption. Only the number of occupants correlated with the amount of water consumed by the house. The variable of Sustainably Designed means the homes that had the sustainable design attributes (the study group homes). The number of occupants is the quantity of people living in the home on average per night and the size of the home is the total rated internal floor area of the house. For this study, the predictor variables are termed independent variables, which are assessed because they potentially have a relationship with the output (dependent) variable of interest (utility consumption).
### Table 9 - Pearson correlations among study variables

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Predictor Variables</th>
<th>Energy</th>
<th>Water</th>
<th>Sustainably Designed</th>
<th>Number of Occupants</th>
<th>Size of Home</th>
<th>Utilisation</th>
<th>Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td></td>
<td>1.00</td>
<td>0.473**</td>
<td>-0.68***</td>
<td>0.66**</td>
<td>0.63**</td>
<td>0.40**</td>
<td>-0.54**</td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>-0.16</td>
<td>0.46**</td>
<td>0.15</td>
<td>0.06</td>
<td>0.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainably Designed</td>
<td>1.00</td>
<td>-0.33**</td>
<td>-0.75**</td>
<td>-0.51**</td>
<td>0.62**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>0.00</td>
<td>0.33**</td>
<td>0.13</td>
<td>-0.41**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of Home</td>
<td>1.00</td>
<td>0.42**</td>
<td>0.57**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation</td>
<td>1.00</td>
<td>-0.61**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preservation</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* *p < 0.05  **p < 0.01  ***p < 0.001

**Energy Consumption Correlations**

As can be seen in the Figure 15 scatterplot, the two estates had quite different energy uses, and one home within each group (cases circled) had an extremely high value for energy use. Outliers for energy consumption within each estate are circled. Both the study group and control group outliers were more than four standard deviations higher than each group’s mean, indicating these are extreme values compared with a normal frequency distribution. Hence these two cases would have been unduly influential on the statistical results, and were therefore excluded from all further analyses involving energy.

Note that the correlations were computed using the transformed energy data; the square root of Energy was used to transform it due to positive skew. For ease of interpretation, the graphs for correlations (below) are presented using raw energy scores so readers can more easily interpret the kWh units. The analysis of the correlation between Sustainable Design and Energy, as depicted in Figure 15, shows
that the probability of obtaining a correlation of this magnitude was 0.001. As this value was less the chosen alpha level of 0.05, the correlation was statistically significant.

Figure 15 - Comparison of average daily energy consumption for all properties

\[ r = \text{Pearson correlation coefficient, } n = \text{number of cases, } p = \text{probability} \]

\[ * p < 0.05 \quad ** p < 0.01 \quad *** p < 0.001 \]

As expected, the analysis showed that the larger houses consumed significantly more energy (as per Figure 16 below), with no home smaller than 200m² using more than 20kWh/household/day. The two groups of houses are also clearly different, with study group examples typically being smaller and using less energy.
**Energy and Environmental Attitude Correlation**

The scatterplot in Figure 17 shows a significant negative correlation between Energy consumption and attitudes favouring environmental preservation, $r = -0.54 \ p < 0.001$. That is, those who indicated they support “conservation and protection of the environment” typically used less energy in their household. For the Preservation scale, converted scores closer to “7” indicate a higher preference to preserve, conserve or protect the environment.
The individual correlations for the control and study group homes EA Preservation and energy consumption showed some trend, but it was not statistically significant.

Congruent with the Preservation results, respondents who more strongly supported Utilisation of resources also consumed significantly more energy (Figure 18). As shown in Table 10, and consistent with previous studies, Preservation and Utilisation attitudes had a statistically significant negative correlation with each other: that is, individuals with high Preservation scores tended to have low Utilisation scores, and vice versa as commonly found using the EAI tool. For the Utilisation scale, converted scores closer to “1” indicate a higher preference to dominate or use natural resources and/or higher confidence in science and technology.
Figure 18 - Energy consumption correlation with EA utilisation responses

An approximate indicator of the strength of the relationship between two variables can be obtained by squaring the correlation which indicates the amount of variance in one variable that is associated with variance in the other variable. This step does not take into account any other variables which are associated with both of the others. For this study, to compare the strengths of the energy-related correlations per capita, the transformed Energy correlations were calculated and then squared, as reflected in Table 10. The results show that Sustainable Design was associated with 34 per cent of the variance in energy consumption per person whereas the two environmental attitude variables were associated with only 14 per cent and 20 per cent. These results could be interpreted as indicating that, within the present study, the sustainable design of a house was twice as likely to reduce a home's energy consumption compared with the influence of pro-environmental attitudes.
Table 10 - Correlations between (per capita) energy consumption and variables

<table>
<thead>
<tr>
<th>Energy Consumption (per capita)</th>
<th>Sustainably Designed</th>
<th>Preservation</th>
<th>Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation (r)</td>
<td>-0.587</td>
<td>-0.377</td>
<td>0.447</td>
</tr>
<tr>
<td>Significance (2-tailed)</td>
<td>0.000</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>Number of samples (n)</td>
<td>67</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>r2</td>
<td>34%</td>
<td>14%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Energy Consumption and NatHERS ratings Correlation

Thirty participants knew the NatHERS star rating of their homes and in these cases the relevant value correlated with the actual energy data (as per Figure 19). A significant negative correlation between rating and energy use \((r = -0.495, p = 0.01)\) demonstrates that houses with higher star ratings used significantly less energy.
In this study no significant difference was found between energy consumption levels in homes dominated with people born overseas (13.8kWh/household/day) and those homes with Australian born occupants (13.4kWh/household/day) – as per Figure 20.
Water Consumption Correlations

Water consumption did not demonstrate a statistically significant correlation with the sustainable design of a home ($r = -0.16$, $p = 0.26$, $n = 52$) as shown in Table 11. Similarly, water usage did not show a statistically significant correlation with house size. However, the correlation of water consumption with the number of residents was statistically significant, as it was for Energy. Environmental attitudes were also uncorrelated with water consumption levels.
Table 11 – Water consumption correlations – both samples

<table>
<thead>
<tr>
<th>Water Consumption (L / household / day)</th>
<th>Sustainably Designed</th>
<th>House Size</th>
<th>No. of residents</th>
<th>Preservation</th>
<th>Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation (r)</td>
<td>-0.16</td>
<td>0.16</td>
<td>0.46**</td>
<td>-0.15</td>
<td>0.06</td>
</tr>
<tr>
<td>Significance (2-tailed)</td>
<td>0.26</td>
<td>0.28</td>
<td>0.00</td>
<td>0.30</td>
<td>0.67</td>
</tr>
<tr>
<td>Number of samples (n)</td>
<td>52</td>
<td>50</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
</tbody>
</table>

* p < 0.05   ** p < 0.01   *** p < 0.001

None of correlations for the study and control group individually (tabled below) were statistically significant. Note that the number of valid water consumption cases was reduced due to poorer quality and quantities of data and this situation is likely to have affected the ability of the data to show any significant relationships.

Table 12 – Water consumption correlations for study group sample

<table>
<thead>
<tr>
<th>Water Consumption (L per household per day)</th>
<th>House Size</th>
<th>No. of residents</th>
<th>Preservation</th>
<th>Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation (r)</td>
<td>0.25</td>
<td>0.34</td>
<td>0.03</td>
<td>0.19</td>
</tr>
<tr>
<td>Significance (2-tailed)</td>
<td>0.31</td>
<td>0.17</td>
<td>0.92</td>
<td>0.46</td>
</tr>
<tr>
<td>Number of samples (n)</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>
Table 13 – Water consumption correlations for control group sample

<table>
<thead>
<tr>
<th>Water Consumption (L per household per day)</th>
<th>House Size</th>
<th>No. of residents</th>
<th>Preservation</th>
<th>Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation (r)</td>
<td>-0.04</td>
<td>0.47</td>
<td>-0.09</td>
<td>-0.11</td>
</tr>
<tr>
<td>Significance (2-tailed)</td>
<td>0.85</td>
<td>0.01</td>
<td>0.63</td>
<td>0.55</td>
</tr>
<tr>
<td>Number of samples (n)</td>
<td>32</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
</tbody>
</table>

Interrelationship between Water and Energy

When comparing consumption levels of the two types of major utility, energy and water correlated significantly. That is, homes which used less energy also tended to use less water and vice versa as shown in Figure 21. However this relation is somewhat weaker than expected; with many high energy consuming homes using little water and some high water consuming homes using little energy.
Given that the only variables that correlated significantly with water consumption were the number of occupants and energy consumption, a partial correlation was calculated to show whether the relationship between water and energy use was accounted for by the number of occupants. The partial correlation, controlling for the number of occupants, was 0.263, \( p = 0.074 \). This demonstrates that overlap between energy and water use was largely due to the relationship of both these variables with the number of occupants.

**Multivariate Analysis**

Correlations were able to demonstrate significant relationships between pairs of variables. Multivariate analysis can provide a more comprehensive and integrated understanding of interrelationships among variables, by including multiple variables.
within the same analysis and thereby allowing additional statistical controls that are not available when analysing pairs of variables in isolation.

As part of the study design, the following factors were controlled for in all analyses:

- Ages of the houses, as a house was only selected if it was 6 months to six years old.
- Climate, as the houses were only selected if they were in the same climate zone.
- Type, as only single detached houses were included.
- Lot size, because only houses on estates with lots of similar sizes were studied.

In the multivariate analyses, controls were added for:

- The number of people in each home, and
- The size of the house.

The variable recording the percentage of time the homes were occupied (labelled “occupied”) was also examined as a potential control variable. It was not included in the regressions because it did not correlate with energy or water use and it did not differ significantly between the two groups of homes. In contrast, earlier analyses demonstrated that both the number of occupants per home and size of home differed significantly between the two settings.

A further advantage of multiple regressions is that, in addition to controlling for potential confounding variables such as occupancy and size of home, the two main predictor types of interest (sustainable design and environmental attitudes) can be directly compared with each other within the same analyses. The results of these analyses are described below with energy and water analysed separately. The two utilities are analysed separately as they are distinctly different measures of utility consumption.
Multiple Regression for Energy Consumption

An hierarchical multiple regression was used to evaluate the combined effects of potential predictors of energy consumption for the model defined in Chapter 1. In Step 1, household operation and demographic characteristics were included. Step 2 included all Step 1 variables as well as the Environmental Attitude variables (Preservation and Utilisation).

In Step 1, household characteristics accounted for a significant amount of variance in energy use: an adjusted $R^2$ of 0.690, indicating that 69.0 per cent of variance in energy use was accounted for by the set of predictors, as listed on page 93. There was a significant beta weight for sustainable design, $\beta = -0.435$, $p < 0.001$, indicating that Sustainably Designed houses used significantly less energy and that this effect remained significant when other housing predictors were taken into account. The squared semi-partial correlation, $sr^2$, indicates that Ecological Sustainable Design uniquely accounts for eight per cent of the variance in energy consumption. The number of house occupants was positively related to energy use, $\beta = 0.455$, $p < 0.001$, accounting for 18 per cent of variance in energy. The size of the house accounted for 1 per cent of the variance in energy use and was not statistically significant ($\beta = 0.154$, 0.146 (ns)).

In Step 2, environmental attitude variables (Preservation and Utilisation) were added. The addition of the two attitude variables did not add significantly to the variability of energy use, once household characteristics were already accounted for, $R^2$ change = 0.01, ns. The overall analysis (Step 2), including both sets of predictor variables, accounted for 68.8 per cent of variance in energy use and was statistically significant, $F (5, 61) = 29.6$, $p < .001$; refer to Table 14. The minor
difference in adjusted $R^2$ between the steps occurs because the adjustment takes into account the total number of predictors and this was higher in the second step.

Both sustainable design and number of occupants remain as significant independent predictors of energy used in Step 2. The result suggests that number of occupants is the largest independent contributor to reduced energy use, which would be reasonably expected and consistent with what Australian Government data report (Australian Bureau of Statistics, 2008 CAT 4102). Interestingly, the sustainable design of a house was the next biggest independent contributor to variance in energy use, not the size of the house. Although EA (Preservation) scores were significantly correlated with energy use, they did not add further prediction of this dependent variable when other house characteristics including sustainable design had already been accounted for.

The square root of Energy was used to transform it due to positive skew. The regression was repeated using untransformed energy to see if using the raw energy data would change the result. There was no resulting change in the statistical significance of outcomes.
Table 14 - Multiple regression analysis of energy consumption

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Step 1</th>
<th></th>
<th></th>
<th></th>
<th>Step 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>( \beta )</td>
<td>( r^2 )</td>
<td>B</td>
<td>( \beta )</td>
<td>( r^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>0.425***</td>
<td>0.455</td>
<td>0.18</td>
<td>0.440***</td>
<td>0.471</td>
<td>0.173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainably Designed</td>
<td>-1.019***</td>
<td>-0.435</td>
<td>0.08</td>
<td>-0.950***</td>
<td>-0.406</td>
<td>0.061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of House</td>
<td>0.002</td>
<td>0.154</td>
<td>0.01</td>
<td>0.002</td>
<td>0.152</td>
<td>0.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation</td>
<td></td>
<td></td>
<td></td>
<td>0.185</td>
<td>0.110</td>
<td>0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preservation</td>
<td></td>
<td></td>
<td></td>
<td>0.073</td>
<td>0.048</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F change</td>
<td>49.293***</td>
<td></td>
<td></td>
<td>0.735</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R^2 ) change</td>
<td>0.705***</td>
<td></td>
<td></td>
<td>0.007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.705***</td>
<td></td>
<td></td>
<td>0.712***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.690***</td>
<td></td>
<td></td>
<td>0.688***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>49.293***</td>
<td></td>
<td></td>
<td>29.617***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* \( p < 0.05 \)  ** \( p < 0.01 \)  *** \( p < 0.001 \)

For the regressions the transformed Energy data were used.

\( B \) = unstandardised regression weight  \( \beta \) = standardised regression weight

Note that the size of homes and number of people per home were greater in the control group estate; however, when multivariate regression testing included these variables, the sustainable design of the house was still found to be a greater independent contributor to the variance in the model.

**Multiple Regression for Water Consumption**

The same regression sequence for energy consumption, was used for water consumption. Step 1 was statistically significant, indicating that the combination of physical and demographic variables was associated with a significant amount of variance in water use, \( R^2 \) change = 0.25, \( p < 0.001 \). Step 2 was not statistically significant, which showed that attitudinal variables did not add to physical and demographic variables in predicting water use. The overall regression model was
significant – see Table 15. Both at Step 1 and in the full model, the only predictor with a significant independent contribution to variability in water use was the number of occupants. In Step 1, the number of occupants predicted 22 per cent ($\beta = 0.50$, $p < 0.001$) of the variance in water consumption.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Step 1</th>
<th></th>
<th></th>
<th>Step 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$B$</td>
<td>$\beta$</td>
<td>$sr^2$</td>
<td>$B$</td>
<td>$\beta$</td>
<td>$sr^2$</td>
</tr>
<tr>
<td>Sustainably Designed</td>
<td>0.02</td>
<td>0.06</td>
<td>0.001</td>
<td>0.01</td>
<td>0.03</td>
<td>0.000</td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>0.07***</td>
<td>0.50</td>
<td>0.224</td>
<td>0.07***</td>
<td>0.53</td>
<td>0.227</td>
</tr>
<tr>
<td>Size of House</td>
<td>0.00</td>
<td>0.08</td>
<td>0.003</td>
<td>0.00</td>
<td>0.10</td>
<td>0.004</td>
</tr>
<tr>
<td>Utilisation</td>
<td></td>
<td></td>
<td></td>
<td>0.02</td>
<td>0.06</td>
<td>0.002</td>
</tr>
<tr>
<td>Preservation</td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
<td>0.14</td>
<td>0.008</td>
</tr>
<tr>
<td>R2 change</td>
<td>0.25**</td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F change</td>
<td></td>
<td></td>
<td></td>
<td>0.250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2 (full model)</td>
<td>0.25**</td>
<td></td>
<td></td>
<td>0.258*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R2 (full model)</td>
<td>0.201**</td>
<td></td>
<td></td>
<td>0.174*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (full model)</td>
<td>5.108**</td>
<td></td>
<td></td>
<td>3.065*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p < 0.05$   ** $p < 0.01$   *** $p < 0.001$

Disaggregating Design and Environmental Attitude

A challenge in interpreting the correlation and regression results is that the Sustainably Designed homes also contained occupants who reported significantly more positive attitudes favouring environmental conservation than occupants of conventional homes. To check effects of design and attitudes separately, it was preferable to compare (a) attitude effects on utility consumption when design was
constant and (b) design effects on consumption when attitude was constant. Both types of analyses were conducted and these results are described below.

**Attitude Effects with Design Held Constant**

The first type of analysis was conducted by calculating correlations between EA and utility consumption within each estate separately (see Table 16). Environmental attitudes towards utilisation or preservation did not correlate significantly with energy or water use within either estate. However, in the study group there was a trend towards lower energy use by residents whose attitudes more highly favoured preservation of the environment and this trend approached statistical significance, $r = -0.306, p = 0.088$.

<table>
<thead>
<tr>
<th></th>
<th>Utilisation</th>
<th>Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy – Study Group</strong></td>
<td>0.213 0.242</td>
<td>-0.306 0.088</td>
</tr>
<tr>
<td><strong>Energy – Control Group</strong></td>
<td>0.031 0.859</td>
<td>-0.150 0.391</td>
</tr>
<tr>
<td><strong>Water – Study Group</strong></td>
<td>0.187 0.457</td>
<td>0.026 0.918</td>
</tr>
<tr>
<td><strong>Water - Control Group</strong></td>
<td>-0.108 0.569</td>
<td>-0.148 0.436</td>
</tr>
</tbody>
</table>

**Design Effects with Attitude Held Constant**

The second type of analysis was accomplished by using the attitudinal data obtained by this study to split the sample into separate groups matched for environmental attitudes. This step was undertaken by taking the median scores for preservation and utilisation and classifying respondents into those above and below the median.

It is acknowledged that the number of respondents in some categories in the median split analyses was low and this point has to be taken into account when
interpreting the results of analyses. Only energy consumption is discussed below, since water differences between the two groups were negligible, unlike energy levels which revealed large and statistically different averages per location.

The median score for all Preservation values was 5.43 on the 1 to 7 scale. Six study group residents were found to have lower preservation scores below this median and 29 control group residents were found to have scores below this median. The means and standard deviations for each group defined by preservation bands and residence type are shown in Table 17.

<table>
<thead>
<tr>
<th>House Design Type</th>
<th>Higher Preservation</th>
<th>Lower Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>n</td>
</tr>
<tr>
<td>Study Group</td>
<td>9.49 (3.46)</td>
<td>26</td>
</tr>
<tr>
<td>Control Group</td>
<td>17.53 (4.43)</td>
<td>6</td>
</tr>
</tbody>
</table>

\(n:\) number of cases

A 2 (Group) x 2 (Attitude) analysis of variance (ANOVA) was conducted for energy use, using the median split for Preservation. There was a significant main effect for “Sustainable Design”, \(F (1, 63) = 24.75, p < .001\). It was consistent with all previous analyses (t-tests, correlations and multiple regression) in showing that such houses were associated with lower energy use than control homes. There was no effect on energy use of being above or below the median score for preservation use, \(F (1, 63) = 1.79, p = 0.185\). Moreover, there was no interaction between sustainable design and preservation attitudes, \(F (1, 63) = 0.74, p = 0.393\). These results show that those living in the study group homes tend to use similarly lower levels of energy
regardless of which environmental attitude group they belonged to. Although it appeared from the means and standard deviations in Table 17 that residents in control homes with preservation attitudes above the median used less energy than residents in control homes with preservation attitudes below the median, this comparison was not statistically significant.

The median score for all Utilisation values was 2.93. Nine study group residents were found to have higher utilisation preferences and 10 control group residents purported to have lower utilisation preferences than the median for all respondents. The means and standard deviations for each group defined by Utilisation bands and residence type are also shown in Table 18.

Table 18 – Energy use of respondents in high and low EA utilisation bands

<table>
<thead>
<tr>
<th>House Design Type</th>
<th>Higher Utilisation</th>
<th>Lower Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Study Group</td>
<td>10.38 (2.90)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>9.37 (3.84)</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Control Group</td>
<td>22.76 (10.04)</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>22.76 (9.55)</td>
<td>10</td>
</tr>
</tbody>
</table>

An ANOVA was conducted for energy use using a median split for utilisation, akin to the ANOVA described above for preservation bands. Similar results to the previous ANOVA were found. There was a significant main effect of sustainable design, $F(1, 63) = 43.47, p < 0.001$. There was no effect of utilisation band, $F(1, 63) = 0.13, p = 0.722$. There was no interaction between home type and utilisation band, $F(1, 63) = 0.24, p = 0.628$. The means in Table 19 suggest a slight trend for study group residents, with pro-utilisation attitudes (i.e., those happy to use more natural resources than conserve them) to use more energy but it was not statistically significant. Those respondents from the control group tended to use the same
amount of energy, regardless of their Utilisation preferences. Again the (sustainable) design of the home overwhelmingly influenced energy consumption levels.
CHAPTER 4 - DISCUSSION

Introduction

The purpose of this chapter is to examine the results and discuss items of significance, such as the degree to which hypotheses were supported, comparisons with previous research, and overall conclusions. The study was designed to explore housing resource consumption associations with sustainable housing design and occupant attitudes. For the most part, the consumption data in isolation are similar to equivalent housing studies conducted in south-east Queensland. The study group stands out as housing that achieves significantly lower energy consumption than the control group but similar water consumption. Interesting the results suggest this is primarily because of the design of the houses and actually not as a result of occupant environmental attitudes or the size of the house.

The overall results highlight the connection between passive design and the operation of the residential houses. Even after controlling for age of housing, lot size and climate, the houses within the study group were found to consume significantly less energy. This result was also found to be the case after controlling for the number of people in each home and the size of the home.

The reduced energy consumption in the study group housing is likely to be attributable to key design features in each of the homes, as mandated by the building codes; they include factors such as the mandatory use of solar based hot water systems, insulation exceeding minimum Building Code of Australia standards, higher specification glazing, optimally sized eaves (to keep the sun out in summer and allow it inside in winter), protected internal thermal mass (to stabilise internal temperatures), efficient lighting and a dark sky policy to minimise lighting consumption and light pollution, to describe just a few examples. This result was
achieved even though the study group housing uses electric pumps for potable water movement, including the transfer of rainwater to each bathroom/kitchen outlet within the homes. It needs to be acknowledged that half of the control group (23 houses) had pools which often use pumps, which are known for their historically high energy demands, whereas the study group shares one pool and other common facilities and this extra energy consumption was not included in the standard analysis. It was estimated that the pool pump, cooking and lighting energy from the central study group facilities would have used approximately 22 kWh per day of energy and, when spread over the number of houses, would only have impacted the average daily consumption by 0.3 kWh. When included in the dataset, this increase had no impact on the statistical significance of the results in the study.

Further analysis showed that the control groups homes with pools (M=28.3, SD=9.1) had a significantly higher energy consumption compared to control group homes without pools (M=17.5, SD=7.2). It is noted that the pools the energy differences between homes with and without pools would also have been affected by the number of occupants; on average there were 3.8 occupants in control group homes with pools, compared to 3.1 occupants for control homes without pools, and this difference approached statistical significance (p = 0.052).

Importantly, the energy consumption of control group homes without pools still significantly exceeded that of study group homes (p < 0.05). In addition, when the presence of a pool was added as a predictor in multiple regression, this variable was a significant independent predictor of higher energy use but the other predictors maintained their relative positions. That is, the largest independent predictor was the number of occupants followed by sustainable design, with pool presence adding a further significant contribution. Taken together, these results show that pools are a
significant contributor to higher household energy consumption but did not explain all the differences in energy use between the control and study group homes in this study.

Electrical and gas energy figures were intentionally recorded separately, as the study group houses use gas for cooking, heating and hot water boosting. The control group uses electrical energy in most cases, since it does not have a reticulated/underground gas supply. However, researchers noted that the Observatory residents are now increasingly installing new solar power systems and, over time, it is possible that these homes could also attempt to negate some of their energy consumption.

In terms of hot water, researchers were informed by residents that at least five solar hot water systems, used by study group homes, were incorrectly plumbed, leading to higher than normal gas use, as the gas boosters operated unnecessarily for several months in summer. Hence gas consumption figures for the Ecovillage could be deemed to be an over estimate, which would merely amplify the effects of the energy consumption results in the study.

Each study group house is required to have a minimum of 1kW of solar photovoltaic panels and in this study, they generated 4.06kWh per day on average. These systems are all “grid connected” meaning that no batteries are used or required. If the central electricity network goes offline, so do the homes, similar to a standard housing estate on grid energy. It is interesting to note that the net energy consumption for some residents with 1.5kW or 2kW solar energy systems in the study group achieve a net zero or positive energy balances. This amount of generation results in these homes having no power bill and the owners receiving a credit (dollar) amount back for the power they are generating and contributing to the...
grid, in excess of their total consumption. It is noted that it would, however, have
taken an upfront gross investment of $10,000 - $14,000 to install such a system but
that there were large rebates of between $4,000 and $7,000 available at the time, as
an added incentive to install them. It is estimated that a photovoltaic energy system
would take 2.3 - 7.3 years to produce enough energy to offset its embodied energy
impact on the environment. They typically last 20-30 years, with a payback period at
current prices being approximately 5 to 9 years depending on the components
installed, location and orientation (Alternative Technology Association, 2009; Lu &
Yang, 2010). Figure 22 graphically demonstrates the types of energy consumed and
generated by homes in the study.

Australian households consume approximately 33.6kWh of energy per day
(Australian Department of Climate Change and Energy Efficiency, 2008) but, when
compared with its peers, the study group still stood out at just 10kWh per day on
average (total energy consumed) whilst the control group homes averaged

![Figure 22 - Energy consumption and generation by type](image-url)
23kWh/day. The fact that both averages are lower than the national average could be due to the fact the housing is relatively new, is able to use more efficient lighting and air conditioning, and contains higher than average insulation compared with older homes. As a comparison, USA housing reportedly uses 29 kWh/household/day (USA Department of Energy, 2001). This outcome suggests there is substantial room for improvement to reduce household energy usage in Australia, even though Australian households on average use similar amounts of energy relative to other developed nations.

As previously mentioned, in a 2009 study titled “The Ecovillage at Currumbin - a model for decentralised development”, a small number of Ecovillage homes were compared with Gold Coast and Queensland State averages for energy and water use per capita (Hood et al., 2010). The earlier study focused on determining the energy used to manage decentralised water systems, in this case rain water collection and treatment facilities. The Hood study found Ecovillage homes used 5.73 kWh/household/day of electrical energy which is only 12.7 per cent less than the findings of the present larger study (6.56kWh/household/day) – see Table 19. These electrical energy figures are a net figure, excluding any power generation. The Queensland Department of Environment and Resource Management led study (Hood et al., 2010) found that Ecovillage homes were using significantly less than the south-east Queensland average and that particular study’s comparison estates as well.
## Table 19 - Average energy and water consumption study comparison

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Observatory (2011 Study)</th>
<th>Ecovillage (2011 Study)</th>
<th>Ecovillage (2009 Study*)</th>
<th>Silva Park*</th>
<th>SEQ*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Energy kWh/household/day</strong></td>
<td>22.76</td>
<td>9.65</td>
<td>9.75</td>
<td>25.75</td>
<td>29.41</td>
</tr>
<tr>
<td><strong>Electrical Energy kWh/household/day</strong></td>
<td>22.75</td>
<td>6.87</td>
<td>5.73</td>
<td>18.91</td>
<td>21.58</td>
</tr>
<tr>
<td><strong>Gas Energy kWh/household/day</strong></td>
<td>0.009</td>
<td>3.34</td>
<td>4.04</td>
<td>6.82</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Solar PV Energy (generated)</strong></td>
<td>0.08</td>
<td>4.06</td>
<td>4.32</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Water (Litres/person/day)</strong></td>
<td>156</td>
<td>173</td>
<td>196</td>
<td>121</td>
<td>134</td>
</tr>
<tr>
<td><strong>Sample Size (houses)</strong></td>
<td>36</td>
<td>33</td>
<td>10</td>
<td>5</td>
<td>Large</td>
</tr>
</tbody>
</table>

* source: 2009 Study (Hood et al., 2010)
Two outliers for energy are excluded in these figures
NA – Not Assessed or known

The south-east Queensland study by Hood et al. (2010) found the six metered Silva Park homes consumed an average of 26 kWh/household/day and an earlier 2006-2008 study reported a consumption of 31 kWh/household/day for the wider subdivision of the same area called “The Gap” (Beal, Hood, Gardner, Lane, & Christiansen, 2008). These levels can be compared with the 23kWh/household/day for the Observatory homes and 10kWh/household/day for the Ecovillage – refer to Figure 23. Consequentially, the control group housing energy consumption averages appear similar to other studies, and the study group results still appear significantly less than other estate and State averages.

In terms of study participants, the 2011 results for electricity use in this study contained 71 per cent more homes than that of Hood and are hence likely to be more representative. Similarly, in the Hood study, the comparison homes were in different climate zones and of differing sizes to the Ecovillage and Observatory sub-divisions.
In relation to electricity use, study group homes used on average 4,884 kWh per annum less than the Queensland State average. In regard to total energy, the study group houses had access to underground gas (LPG) which provides energy for cooking (stoves and ovens) and a backup for the solar hot water systems which are mandatory. After converting the gas (from litres to kWh), the relative energy component of the supplementary gas systems adds an extra 3.4kWh per day, taking the study group total energy consumption to 10 kWh/household/day. This level is still far less than homes of a similar age at The Gap at 31kWh/household/day (Beal et al., 2008) and Silva Park homes at 26kWh/household/day (Hood et al., 2010) (Table 19). The primary reason for this difference is likely to be the designs of the homes; all homes within the study group must use solar passive design, cannot have...
individual pools (and hence pumps) and do not use air conditioners. These design requirements include ensuring that the building orientation utilises solar north to maximum effect, eaves protect homes from the sun in summer but allow it inside during the winter, and insulation and glazing types suit the local climate. Electric hot water systems were standard in Australia until recently and the increasing take-up of solar hot water systems would be reducing the energy and GHG emissions for the study group homes, as would the use of gas instead of electrical power (in Australia). Equipment uses also differ: non-Ecovillage homes often contain pools (and hence pool pumps) and are larger in size (GFA). The study group homes also “preference energy and water efficient appliances” and air conditioning is prohibited (and not required) which some find unusual given the sub-tropical hot humid climate.

In 2011 Newton and Meyer found that individual effects of appliance acquisition are linked to age and occupation in Melbourne. That the houses occupied by high appliance users had higher energy ratings is suggestive of a Jevons effect. The effect describes cases in which, increases in the efficiency of appliances, tend to increase the rate of consumption of that resource rather than decrease it; for example, where energy savings from the operation of the house are merely shifted, to increased appliance purchase and use (W. P. Newton & Meyer, 2011a). It cannot be determined that the Jevons effect was in place in the sustainably focused homes without more qualitative analysis. However, the results of the present study suggest that, regardless of (possibly more) appliance use, homes designed with a sustainable and energy efficient focus can reasonably expect to reduce power usage overall, using sound design principles. The Melbourne precinct study found a similar correlation between housing space and energy use ($r = 0.44^{***}$) (W. P. Newton &
Meyer, 2011a). It also demonstrated that Australian born people consumed significantly more energy on average than Australian residents born in other countries which contrasted with the results of the present study which found no correlation.

The strong statistical relationship found in the present study between high a NatHERS star rating of homes and low energy use supports the belief that NatHERS tools can predict relative energy performance in houses. It is acknowledged that this computation involved only 30 homes and that to be considered truly representative, such results would need to be confirmed using a larger sample size across a range of homes and for different climate zones. It is also acknowledged that NatHERS tools only provide heating and cooling load predictions, but heating and cooling loads are a high proportion of energy use in most homes so results would be expected to behave in a similar direction; that is, NatHERS results should correlate with total energy consumption, but never perfectly due to other energy components; for example, lighting, pumping, and appliances.

When comparing water consumption, the groups were found to use a similar amount and this outcome was not found to differ significantly in relation to the design of homes or other factors. However, the study group has its own internal water cycle and management system which takes no water from the town supply, whereas the control group housing uses primarily town water. Australians on average consumed 103 kL of water per person per day (Australian Bureau of Statistics, 2010b) during 2004–05 when the average household size was 2.6 persons per house (Australian Bureau of Statistics, 2005). However, this figure includes units, apartments and townhouses which could have few or no gardens (impacting...
water demand). The higher figures from the study group (173L/person/day) and control group (156L/person/day) can probably be explained by:

a. Water restrictions applied in the Gold Coast City Council region during the research period due to drought conditions affected the control group housing. The study group housing has its own internal water cycle so such restrictions do not apply. The only way the study group could run out of water is if the recycled water reserves diminish and insufficient rain falls and extinguishes all tank water reserves at the homes and shared facilities. At this point they would have to rely on expensive transported tank water.

b. Study group residents having real time monitoring systems in their homes and having to maintain their own rainwater tanks, potentially making them more aware of their water prosperity and encouraging/allowing them to use more water when they know their tanks are staying very full (during wet seasons).

c. Study group residents having larger gardens, growing some of their own food and hence using more water, especially to establish them in the first few years of operation.

d. 50 per cent of control homes having pools, which require more water in hot periods.

The earlier 2007-2009 study (Hood et al., 2010) of a small sample of Ecovillage homes found water usage to be higher than the Queensland State average over the two year period (196 L/person/day versus 180 L/person/day). This figure is slightly higher than the 173 litres per person per day calculated from the present
study. The Australian Government figures (Australian Bureau of Statistics, 2005) equate to 268 litres per household on average, compared with 488 L/household/day for the control group and 426 L/household/day for the study group. Interestingly, the study water consumption figures switch (see the section starting on page 105) when comparing the per person with per household figures. The study group individuals use more water, which is likely to be caused by there being more people in the control homes, spreading the “common/shared” water load and achieving a minor economy of scale.

The groups used different water systems, with the control group using a potable town-water based system. For the majority of the study group homes using the independent isolated water system (all homes in Stage 1 and 2 of the development) internally used water flows to a wastewater treatment plant. This system treats all household grey and black water, and then recovers water that is made available back to the homes, providing them with a recycled water source for all toilets and external irrigation on gardens. As a result, no waste water is added to the load of the local town (potable) water system. In this sense it is difficult to equate the water usage of the two groups on different scales due the significant differences in their water sources and systems.

To evaluate the full lifecycle costs of the water arrangements of the two groups, the price of supplying water would need to be considered as previously studied in 2008 (Kenway, Priestley, & McMahon, 2008). This provision was outside the scope of the present study which limited itself to water usage within the boundary of the homes. It is also acknowledged that only operational impacts were studied and that the embodied energy of all the homes would need to be included in any full lifecycle assessment analysis.
As shown in Figure 21, homes which used less energy also tended to use less water and the reverse was found to be also true. A partial correlation showed that this association was largely accounted for by the increased utility use for both energy and water associated with a larger number of occupants. This is consistent with previous findings in the literature (Australian Bureau of Statistics, 2008; Manfred et al., 2004). The present study found that the number of occupants correlated more strongly with energy than with water use. There were additional variables associated with energy use that were not associated with water use. This indicates that approaches may be needed when trying to influence consumption of different utilities.

Environmental Attitude Trends

The comparison between Environmental Attitudes and utility consumption for the separate estates found no significant correlations (refer to Table 16 in the previous chapter) but trends indicate that, those people in the study group with higher pro-preservation attitudes can contribute somewhat to their homes using even less energy. This trend was not seen in the control group responses which could suggest that the lack of sustainable design attributes in those houses stops residents (who have higher environmental preservation attitudes) from being able to reduce their energy consumption. For example, the less solar passively design homes with too much external unshaded thermal mass (or black roofs as seen in some of the control group housing) might retain excessive heat at night in summer requiring the use of mechanical air conditioning to maintain acceptable indoor temperatures, regardless of any (unsuccessful) attempts by the occupant to try and ventilate the house. Other examples might include turning lights off, closing blinds and curtains, and actively using fans but if these features are not installed it could limit occupant capabilities.
Alternatively this trend could be explained by residents having different financial or comfort priorities or knowledge about what actions can actually save power. That is, a resident could prefer to act in an environmentally friendly way and aim to reduce his or her energy use, but only after other priorities have been met, such as having a pool, larger televisions or more appliances.

Hypothesis Review

This section evaluates each hypothesis using the results of the study, as prepared in Chapter 1.

The first question of interest asked “how do sustainably designed residential buildings compare with conventional homes in the same climate zone (in south-east Queensland) in terms of operational resource consumption?”.

The derived hypothesis (1) predicted that “sustainably designed residential buildings will demonstrate significantly lower utility usage compared with conventional homes”. Resource consumption was measured through energy and water consumption, since they are the primary forms of utility consumed by residential buildings. The energy results support hypothesis 1 because:

- T-tests demonstrate the mean gross energy consumption of sustainably designed homes of 9.65kWh/household/day (3.6) was significantly lower than that in conventional homes 22.76 (9.8),
- Energy data correlated negatively with those homes identified as sustainably designed (r = -0.685 (0.000) n=67), implying they used significantly less energy, and
- When used in a multiple regression with other variables that were considered likely to explain the relationship to energy use (house size, number of people and environmental attitude), the number of people explained the largest proportion of energy use, followed by the sustainable design of a home. This
result indicated that sustainably designed homes in the study used significantly less energy even when other factors had been statistically accounted for.

The water results did not support the Hypothesis 1 because:

- T-Tests demonstrated the mean of water consumption of sustainably designed homes was not significantly different (426L/household/day on average for the Ecovillage) relative to 488L/household/day used by the control group homes,
- Water data did not correlate significantly with those homes identified as sustainably designed (r = -0.160, p = 0.25, n =52), that is, the two groups consumed similar levels of water on average, and
- When used in a multiple regression with other variables that were considered likely to explain the relationship to water use, the sustainable design of the house was not able to explain a significant amount of water use.

Hence hypothesis 1 was supported for energy consumption but not water consumption.

It would be reasonable to conclude that the major energy conservation measures mandated in the development codes applying to the group of sustainable homes are likely to have facilitated the reduction in energy consumption. Moreover, the passive design of a house had a large influence, compared with the attitudes and actions of residents within the homes.

The second question of interest asked "what impact do environmental attitudes (EA) have on household utility usage?" The derived Hypothesis (2) predicted that residents with stronger pro-environmental attitudes would demonstrate lower utility use. The data (as a single set) indicated there was a signification correlation between the environmental attitudes of occupants and their
energy use (Preservation correlation:-0.539** and Utilisation correlation: 0.403**) as shown in previously in Figure 17 and Figure 18. However, when analysed separately, only a (non-statistically significant) trend towards lower energy use could be seen by Ecovillage residents with higher Preservation scores (see Table 16). There was no relationship found between a resident’s environmental attitude and water consumption – see Table 12 and Table 13. Hence the hypothesis was supported, but only in limited isolated instances.

The simplistic (correlation based) analyses did not take into account the location of the participants (Ecovillage or Observatory) or the design (attributes) of the housing so other factors contributing to the lower energy use were investigated using multiple regression analysis, which enabled control for major variables. Such results are described below as part of Hypothesis 3.

The final question of interest was “What is the relationship between sustainably designed residential buildings and an occupant’s environmental attitudes (which contribute to a building’s operational performance)?” The derived Hypothesis (3) predicted that houses designed with sustainable design principles and containing residents with higher environmental consciousness would demonstrate lower utility use.

In these data, when the environmental attitude scores were combined with other major determinants such as how sustainable the homes were, and basic house size data to allow for house characteristics, the design of the home had an overwhelming effect. This occurs because the attitudes contributed no further significant value to the relationship (evaluated via regression). Refer to Chapter 3 for details.
When analysing the two groups separately, there was a trend towards “preservation” being associated with lower energy use in the sustainably designed study group homes, $r = -0.306$, $p=0.088$. However, the correlation was not significant for the control group homes, $r = -0.150$, $p=0.391$. The environmental “utilisation” attitude correlations revealed no significant relationship with either the study or control group.

When the water data from sustainable homes were analysed, there were no significant correlations or trends, between sustainable homes and the environmental consciousness of their occupants (utilisation or preservation) and water use. Hence there is little evidence from this study to support the hypothesis that buildings housing residents with higher environmental consciousness demonstrate lower utility usage, with the exception that energy can be impacted slightly by those wishing to preserve the environment, but not those who are anti-utilisation.

Levels of environmental consciousness might not be impacting utility use for several reasons. First, a mechanism called cognitive dissonance, which persuades people to give up ambitions that appear to be impossible to achieve, could be at play. That is, they could have a certain level of consciousness but it does not translate into behaviours and actions. Second, people may be confused about which actions make the most difference to reducing their own utility consumption. For example, few people understand that using a pool pump or eating meat can significantly increase a person’s ecological footprint, compared with say turning off a light between uses, which feels significant but is further down the list of priorities when comparing resource conservation options that make the most net difference.

Newton and Meyer reported that a limited number of studies of resource usage have identified gaps between people’s attitudes/beliefs and their behaviours
and actions. Thus, even if people had good intentions, their attitudes might not translate to more sustainable behaviour and hence reduced energy or water consumption. This disjunction could occur because they have an overly enhanced belief that they act sustainably or because they act in ways that do not impact their overall consumption significantly.

In terms of operational costs, control group residents’ bills are much higher for water, electricity and local (Gold Coast City Council) rates. However, the study group residents pay body corporate levies (to cover internal wastewater treatment and waste removal) which negate some of the local council fee savings. Study group residents also invest in renewable energy and large water tanks when building their homes so the payback for such capital investments would have to be considered in any financial comparison. Indeed some could argue that the non-financial (for example social) benefits of living in these particular homes and estates would outweigh the on-going operational costs that are incurred by owners and hence reflect their initial decision to purchase land parcels in their respective areas.

Both electricity and water costs are heavily subsidised by governments to ensure that basic services are available to all residents (Levine et al., 2007). Water infrastructure is often funded by taxes to provide water security, for example, the government funding of the sea water desalination plant at Tugun, Queensland, near the communities in this study.

The artificially low prices inadequately reflect the real environmental, social and economic costs of supplying such services. As a result, consumers have fewer incentives to build or operate their homes more efficiently. If the full costs were passed on there could be a change in the way people design, construct and operate buildings; but it would increase the average cost of living as basic services became
more expensive in the short to medium term. This point suggests that identifying, reporting and promoting the long term financial savings and non-tangible benefits of sustainable buildings (such as lower toxicity and better air quality) are worthy of more attention.

A study of 221 sustainable homes in Germany, Sweden, Austria, Switzerland and France demonstrated the “functional viability of Passive House concepts at all sites, the achievement of the space heat savings target, ... project-level economic viability and a high degree of satisfaction of building occupants” (Schnieders & Hermelink, 2006, p. 20). Consequently it would appear possible to design and operate sustainable houses in several parts of the world and in different climate zones. The study concluded that initiatives like demonstration projects may be needed to disseminate knowledge about which construction and design methods are important to overcome the initial scepticism of builders and consumers. Furthermore, government could financially support demonstration and dissemination via guided tours, case studies and distribution of information material. Reducing cost and increasing benefit and transparency through live case studies are merely ways to invoke an economic “market pull”. Others include incentive programs and rating systems that reward quality sustainable performance. In some regards, house buyers are currently being pulled by the market in Australia into buying conventional and contemporary housing stock, as this is the standard offering and norm, in the relative absence of more sustainably designed stock at the same price point.

Outlying Data Investigation Results

The research was able to identify one home from each group which appeared to have unusually high energy levels compared with all other homes in their cohort. On further investigation:
a. The owners of the housing within the control group informed researchers that they were in a dispute with their energy company about some very high meter readings, suggesting there could have been a fault with the meter.

b. A study group owner was grateful for being told that her electricity bill was more than twice the average and this led to testing and finding that their freezer was responsible for much of this abnormal usage (accounting for 5.34 kWh per day). The appliance has since been replaced with a more efficient model.

Study Limitations and Strengths

The study had a number of characteristics, limitations and exclusions and that made it unique. They are described below and include:

- same climate, house ages and meter accuracy
- sample size and response rates
- (more accurate) meter/billing data
- (longer) data recording periods
- non-operational embodied energy
- economic, social or financial benefits of reduced utility usage.

The study was able to incorporate several factors that make it unique. Because both the sustainably designed and comparison estates were in the same area, the climate and other related differences could be assumed to be similar. In the geographical sciences, studies have demonstrated the role that space and place play in consumption so it was beneficial to have been able to account for these factors (Goss, 2006; Mansvelt, 2008; Perkins, Hamnett, Pullen, Zito, & Trebilcock, 2009). Real time data from study group houses supplemented utility meter and billing data.
and allowed more extraneous data to be identified and removed from the study to enhance its accuracy. For example if a gas meter had a leak, gas data for the specific house during the period between leak detection and its subsequent rectification could be omitted from the household’s average energy use, whereas billing data from utility providers did not allow for such interrogation.

In regard to house size, whilst the size of homes in the intentional study group community was smaller than the comparison group, this disparity is likely to be due to the codes and guidelines for housing design in that precinct, as opposed to merely financial constraints which could have impacted owners.

In terms of limitations and constraints, the sample size, relative to full population, was reasonably small and it limited the statistical power of the study. However, similar studies combining utility use and attitudes over populations of more sustainable and less sustainable homes do not appear to have been attempted before. It would also be practically very difficult to survey any larger number of sustainable homes in Queensland, given the constraints which included the budget and time, occupant interest, the fact that the other sustainable homes are widely distributed around the Queensland, the fact that there are not that many of them and that their ages differ widely. Seventy percent can be seen as a relatively high response rate for the study group estate; refer to Chapter 2 for more detail.

The response rate for the conventional estate was more challenging because the research team was limited by the recruitment method that was permitted by the overseeing ethics committee, which included only contacting homes by mail. Similarly, many of the target occupants had children and it is likely that most of the adults had full time employment, making responding to a survey a low priority for
them. It is separately acknowledged that one adult responded per household who might not have been representative of all occupants.

In regard to water and weaknesses, some of the meters within the study group were unreliable and those with false or no readings were removed from the study. However, most homes use more power in the relevant climate zone during summer and winter peaks (for cooling and heating respectively) so for those homes that had fewer than 12 months of bills (36 out of 75), the average energy consumption could have been skewed. This effect would have applied to all homes reducing this potential bias. The fact that the energy consumption for the conventional homes of 23kWh/household/day was close to the average for local south-east Queensland area of 29kWh/household/day (Hood et al., 2010) suggests the energy data were reasonable and reliable.

It is acknowledged that the results cannot directly be generalised to the wider Australian population but comparison to geographical averages was possible for metrics that were equivalent, for example, litres of water consumed per day (per household or per person). Furthermore, the study used a comparative approach to analyse two estates that had some very similar characteristics but also some fundamentally different (design) features. It captured historical utility data which improved the quality of measurement compared with studies of only a single billing period. Attitudinal data were collected at only one time so the study had to assume the attitudes did not vary significantly in the past, for example, enough to effect their energy and water usage over the past six years.

The scope of the study did not include the non-operational embodied energy (Treloar, Fay, Love, & Iyer-Raniga, 2000) that is inherently part of a new house. Embodied energy is the energy used to produce, transport and install the steel,
concrete and other resource intensive materials which go into constructing a house. It is however, acknowledged that this factor is important for any assessment of the full lifecycle of buildings. The number of appliances per house was not recorded and could have been used to compare data with other studies; for example, the Melbourne precinct study by Newton and Meyer (2011b). Other consumption measures, such as waste, air quality, transport, food and other factors could also be included in additional studies with wider scopes.

The study did not attempt to calculate the economic, social or financial benefits of reduced utility usage, but it is likely that, in most cases, lower utility usage would result in lower total operational financial costs, in this case to the consumer. Reduced utility usage would also suggest lower environmental impacts (reduced GHG emissions). The scope did not include an evaluation of the return on investment attributable from the capital costs incurred to employ sustainable design measures; for example, the payback on installing solar photovoltaic energy systems (Kothari & Miotello, 2010).

Collection of a range of demographic data also permitted adjustment for various physical and demographic characteristics. For example, utility data could be correlated with attitudinal data from the same sample used to measure the impact of sustainable design, unlike other studies that have typically focused only on consumption data or attitude.

Further Research Opportunities and Concluding Remarks
This chapter summarises the research results and then identifies opportunities for further research. The study compared primary household resource utility consumption of two comparable estates. The impact of major variables such as the sustainability of housing design, size of house, hours occupied and the number of
occupants were analysed using demographic, consumption and environmental attitude questionnaire data.

Further research could attempt to replicate the present methodology and corroborate or challenge these results. Additional studies that would extend this project include appliance assessment and exploration of transport and energy determinants.

a. One recommended inquiry would involve recording the quantities, types and usage of household appliances within houses, to enable direct comparison with previous data (W. P. Newton & Meyer, 2011b). Embodied energy from house construction would also be included in more comprehensive models of environmental impact.

b. Studies of transportation could estimate the energy required to carry people and goods to and from the houses, and would provide an additional view on the aggregate residential sustainability by incorporating house density and location perspectives. That is, do residents living in homes that are built in more rural or peri urban areas, further away from public transport and services, use so much extra energy on transport that it negates the benefits of living further afield? In addition, are detached houses with room for food (vegetable/fruit/meat/dairy) production, utilised for such farming and does this significantly reduce the travel required to support a more rural existence? Note that study group residents suggested to researchers that they regularly shared resources as well which meant they could “avoid” having to travel outside their estates for many days. Such actions suggest that, if residents can reduce their transportation costs and utility bills
while maintaining or increasing their levels of well-being, this behaviour could be proposed as a positive model for reducing impacts on the environment without negative side effects. Holden and Norland (2005) found, via a survey of eight residential areas in Oslo, data that support the theory that a compact city is a more sustainable urban form, however, decentralised towns with strong central cores can also lead to lower energy use in households. The study results indicate that whilst everyday travel in densely populated areas decreases, travel by plane increases, and in addition, that those with access to a private garden tend to travel less during leisure time.

c. Using the data from the present study, additional research could now compare external energy consumption such as the energy used by the waste water treatment plant. The current study group uses a dedicated waste water treatment plant for all grey and black water. It uses 1.1 kWh/kL, which compares favourably with the specific energy of the Gold Coast recycled water of 1.4 kWh/kL, inclusive of energy for membrane filtration and ultraviolet sterilisation (Hood et al., 2010, p. 4). This is more energy than the specific energy of seawater desalination from Tugun (0.5 kWh/kL) and less than the estimate for the town “purified recycled water” system at 4.6 kWh/kL (Gardner et al., 2008, p. 9) suggesting local treatment is not always a more expensive mechanism.

The capital price of the homes could also be compared, however ideally this should be compared with the operational costs over the lifetimes of the housing. It could certainly be argued that because affordability is part of sustainability, homes such as those studied, could be rated as economically unsustainable when comparing
capital cost criteria, because new homes in Australia are some of the most unaffordable in the world (Daly, 2010). That is, if the average family cannot afford to purchase a home then perhaps new models of finance incorporating the longer term savings are required.

The patterns of energy use over a calendar year could also be extracted from the monitoring system data if other researchers were interested in how the “sustainable” houses compared, during different seasons or external/climatic conditions. For example, perhaps one group of homes are able to perform better in summer than another, but not in winter, with impacts on energy use and personal levels of comfort and hence, satisfaction. It would be particularly interesting to determine if control group occupants report improvements in internal comfort, derived from their use of mechanical HVAC systems, compared to the study group whose housing relies primarily on passive cooling design.

The last recommendation involves understanding the reasons behind the results found in this study. Qualitative interviews of respondents should provide a more in depth explanation of the causes for lower energy use in the study group and any perverse outcomes, which were mentioned by occupants. Understanding the differences in environmental attitudes and the perceived links between these and actual behaviours could also be beneficial. Indeed interviews of residents with more extreme attitudes and utility usage patterns could be targeted initially, to see if patterns exist to explain the findings of the study.

It would be naive to predict that attitudes have no impact on the operation of housing and for homes known for their “sustainable” features. However, the impact of such knowledge requires more research due to the complexity of relationships among attitudes, behaviour, prior experiences, capabilities and operation of the
home. More comprehensive studies should incorporate indoor environment qualities, user experiences and occupant satisfaction, which would make relationships easier to identify.

In terms of the housing sector, the popular rising of so-called “sustainable” homes has created a new “green development” sub-sector in the property industry and it, combined with the investment finance resulting from the Carbon Tax (Sandell, 2012), suggests there is a significant need for more research to support imminent programs. Property valuers are only just starting to catch up with the release of new indices such as IPD’s Sustainable Property Index and Australian Green Index, but they are far from perfect. IPD states that “given the very small sample sizes and the fact that sustainability factors have not yet been priced into the market valuations ... recent performance numbers must be treated with a high degree of caution” (Investment Property Databank, 2011b, p. 10). These performance numbers currently show green buildings deliver significantly more financial return compared to standard buildings, as reported on page 30. Such caveats suggest there is a significant need for more research in the area of sustainable development, to support government and industry to understand how to adjust designs and incentives to encourage more sustainable ways of living.

Analysis of the data suggests the sustainable design of housing contributes significantly to reducing its energy use. In the case of the study group, which contains homes that must meet comprehensive sustainable design criteria, average gross energy use was 58 per cent less than that of the comparable control group when not taking into account the power generated by households. Each study group home is required to install a minimum of 1kW of solar photovoltaic panels and, on average, the cells generated 4.1 kWh per day. Some residents with 1.5 kW or 2 kW
solar energy systems were able to ensure that more energy was created than they used, triggering their utility companies to credit them, rather than having to pay for electricity. When taking into account the power generated, the study group homes used just 5.7 kWh of grid power per day on average. This figure was 75 per cent lower than the net energy use of the control group houses, which consumed energy at an average rate of 23 kWh per day. This is a considerable difference and clearly highlights a key area of inefficiency in current conventional building standards. It also demonstrates the unsustainable nature of standard contemporary housing currently being constructed in Australia.

Predictably, the difference in greenhouse gas emissions was also significant, with the Ecovillage emitting 87 per cent less GHG on average than the control group. This analysis did not take into account any use of GreenPower by residents, and if the study group favoured this more expensive but emission free energy option, due to their greater pro-environmental attitudes, this would make the difference in the group’s emissions even larger. Industry leading commercial green buildings have been shown to reduce carbon dioxide equivalent emissions by 34 per cent on average (Fowler et al., 2010). So it would appear that there is vast potential to reduce emissions, by implementing (and possibly having to impose) sustainable design principles to the relatively immature Australian residential sector.

A lower level of energy and water consumption might be associated with a lower Quality of Life if access or financial constraints exist. In this study, the residents in the environmentally intentional community still arguably share a high Quality of Life (Upadhyay & Hyde, 2011) since they have access to the same comfort opportunities, resources and utility services. Most households, for example, have the same appliances and luxuries one would associate with a high standard of
living; large televisions, a pool, multiple kitchen appliances and high speed internet access. Hence it appears possible to enjoy high living standards, without consuming as much energy as the average current Australian household, if some technologies and supportive smart design is incorporated.

As expected, the number of people in each household correlated positively with the amount of energy consumed. The size of a house correlated initially with energy use but, when included in a model with other variables more strongly associated with energy use, house size did not have a statistically significant independent association with energy use. In terms of water, differences in consumption were not statistically significant with both estates using a similar amount of water and this outcome was not found to correlate with other data.

The results from the environmental attitude questionnaire were not able to demonstrate that environment-based attitudes and behaviours contributed significantly to lower energy use, when other demographic housing design factors had already been taken into account. However, people interested in preserving the environment tended to use less energy when considering just these two variables.

Given that a squared correlation can indicate the amount of overlap in variance that is shared by two variables, it can be seen that the sustainably designed houses were associated with 34 per cent of the variance in energy consumption per household whereas the two environmental attitude variables were associated with only 14 per cent and 20 per cent of the variability in energy. From the particular sites chosen, this finding suggests that the sustainable design of a house is twice as likely to reduce its energy consumption compared with the influence of pro-environmental attitudes.
Given the results suggest that those people in sustainable housing tend to use less energy regardless of attitude, support for Government policies that mandate higher (minimum) levels of energy performance could be seen as justified. The financial costs of such design improvements should naturally be first confirmed to ensure net impacts truly result. However, a 2011 report commissioned by the Victorian Government for the Cape Patterson Ecovillage estimated the cost difference of building 6-star and 7.5-star homes was $27,000 (Szatow, 2011). The report was able to then conclude that cumulative savings on energy bills and mortgage payments could exceed $300,000 under a high future energy price scenario, more than offsetting the upfront capital expenditure. Hence it could be argued that sustainable design can demonstrate the financial benefits today as well as less tangible benefits.

The main barriers to such improvements being mandated appear to be industry bodies trying to protect short term property jobs and the lack of focus on education of prospective buyers and property valuers who influence mortgage calculations by home loan lending institutions (Short, Minnery, Mead, O'Flaherty, & Peake, 2006). Inconsistent legislation has also been identified as a barrier, so policies addressing issues such as these, by leveraging the outcomes of this study are likely to produce more desirable residential housing outcomes. Indeed the results suggest that stronger prioritisation of sustainable design principles in housing development can significantly reduce human-initiated environmental impact, whilst still providing all the amenities, services and facilities of conventional housing.
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the World Commission on Environment and Development: our common future.*

APPENDIX A – Research focus and relationships

Personal Characteristics
Demographic Data

Sustainable Design & Contemporary Design

Utility Usage

Metering Data

Environmental Attitude
Questionnaire

Perceived Residential Environment Satisfaction (PREQ) Questionnaire

Analysis of utility consumption and attitude impact on utility use

Neighbourhood satisfaction results to examine people–environment congruity to predict Environmental QoL (QoL_e)

Key

Masters Study focus (this Study)  PhD Study focus  Shared
APPENDIX B - The Hannover Principles for Sustainable Design

1. Insist on rights of humanity and nature to co-exist in a healthy, supportive, diverse and sustainable condition.

2. Recognize interdependence. The elements of human design interact with and depend upon the natural world, with broad and diverse implications at every scale. Expand design considerations to recognizing even distant effects.

3. Respect relationships between spirit and matter. Consider all aspects of human settlement including community, dwelling, industry and trade in terms of existing and evolving connections between spiritual and material consciousness.

4. Accept responsibility for the consequences of design decisions upon human well-being, the viability of natural systems and their right to co-exist.

5. Create safe objects of long-term value. Do not burden future generations with requirements for maintenance or vigilant administration of potential danger due to the careless creation of products, processes or standards.

6. Eliminate the concept of waste. Evaluate and optimize the full life-cycle of products and processes to approach the state of natural systems, in which there is no waste.

7. Rely on natural energy flows. Human designs should, like the living world, derive their creative forces from perpetual solar income. Incorporate this energy efficiently and safely for responsible use.

8. Understand the limitations of design. No human creation lasts forever and design does not solve all problems. Those who create and plan should practice humility in the face of nature. Treat nature as a model and mentor, not as an inconvenience to be evaded or controlled.

9. Seek constant improvement by the sharing of knowledge. Encourage direct and open communication between colleagues, patrons, manufacturers and users to link long term sustainable considerations with ethical responsibility, and re-establish the integral relationship between natural processes and human activity. (McDonough et al., 2003)
APPENDIX C - Summary of Ecovillage Guiding Principles

Environmental Principles

Restore, maintain and enhance biodiversity.

Strictly minimise impact and change to air, soil and water.

Strictly minimise consumption of resources and energy both now and in the future.

Minimise impact on the local and global environments optimising local ecological food and material production opportunities.

Foster a deep sense of human connection and interdependence.

Social Principles

Respect and honour cultural, historical and spiritual values.

Enable sustainable community by designing for social equity, diversity and interdependence, honouring differences and catering for the needs of individuals through the different stages of life.

Maximise health, safety and comfort of the built environment.

Utilise aesthetic sensitivity to create a continuing sense of place and beauty that inspires, affirms and ennobles.

Economic Principles

Promote Ecovillage economic viability through excellence of design.

Ensure enduring property value growth.

Ensure minimising of maintenance and operational costs.

Enable economic productivity and contribution to local and world systems and economies.

Minimise obsolescence through design of enduring component life cycle.

(Landmatters Currumbin Valley Pty Ltd, 2005)
APPENDIX D – Letter to Participants
Request for your participation in local research

Information Letter

Study Title: Towards a Quality of Life Model for Sustainable Housing in south-east Queensland

Dear Resident,

In 2010 and 2011 a team based at The University of Sydney in collaboration with The University of Queensland, will be conducting research on homes in SE Queensland to provide a better understanding of Quality of Life in relation to residential developments. We are predicting that the results will provide substantial insight with the potential to influence future housing and development policy and government spending.

Homes in your local area have been selected as candidates for participation in the study given the local housing mix, climate and weather.

If you are able to assist with this research by participating in the study, we would be most appreciative. Attached is a Participant Information Statement that provides more details of the study and what your participation would involve. The research has been approved by the University’s Human Research Ethics Committee.

All participants will be offered compensation for their time at a nominal rate. Participation is of course optional.

To participate in the study or obtain more information, can you please:

Email researcher Ben O’Callaghan at ben.ocallaghan@sydney.edu.au

or

Return the attached form, using the enclosed envelope

or

Phone a Researcher to register:

Ben O’Callaghan: Xxxxxxxxxx or

Anir Kumar Upadhyay Xxxxxxxxxx

A Researcher will then get back to you in 3-6 weeks with more details and arrange a time with one adult representative of the household.

Thank you for your time and interest.

Professor Richard Hyde
Quality of Life Study Participation Return Form

You can return this page using the envelope included

To:
Professor Richard Hyde
Room 588
Wilkinson Building (G04)
University of Sydney NSW 2006
AUSTRALIA

Dear Professor Hyde,

I have received the request to participate in your local research titled: 'Towards a Quality of Life Model for Sustainable Housing in south-east Queensland'

Please tick one:

☐ I may be available to participate in the research and your researchers may contact me to provide me with more information.

or

☐ I am unwilling or unable to participate in this research.

Kind regards,

Your Name: .................................................................

Your Address: ........................................................................

My contact details are below:

Email: ........................................................................... and/or

Phone: ............................................ (bh) or
................................................................. (ah) or
................................................................. (mobile)

Today's Date: ............................................
APPENDIX E – Questionnaire
PART 1  Survey for All Home Owners

Demographic Data Collection
Data Collection Survey for Residents
Office Use Only
    House ID: __________
    Date of survey completion: ______________

Introduction
Thank you for your participation in this study.
This questionnaire contains basic demographic questions.
The questions are optional. Please use estimates where you need to.
The questions refer to all people normally residing at the premises.

Address of House: _____________________________________________________

Resident (representative):
First Name: ______________________
Surname: ______________________
Email address: ___________________________________________

Months lived at this address: _______

House Build (completion) Date: ____________________

Number of Occupants:
Number of occupants sleeping in the house on average: __________

This is the number of people who use the house as a place to sleep. For houses with variable occupancy, a time-weighted average of occupancy throughout the year is used, excluding any periods when the house is completely empty.

Occupant Hours
Total hours that your house is usually occupied (by at least one person) from 7am to midnight, on average per week: __________ hours

How many weeks was your home unoccupied during the last year (to time you have been in this home)? _______ weeks

Size of home (total rated internal floor area): _______
Total floor area of the habitable part of the house is measured to internal faces of external walls of each separate storey of the house. Areas of unheated or inhabitable spaces such as integral or attached garages, separate conservatories, garden rooms, etc. are not included.

Postcode:__________

Total area of house site (lot): _________m²
This is the total area of the block of land within which the house sits.
Number of Swimming Pools in use ____ (and size ____ in litres)
Number of bedrooms: _______
No. of bathrooms: ________
Age of occupants:

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of people in household</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td></td>
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<tr>
<td>5-9</td>
<td></td>
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<td></td>
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<td>15-19</td>
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<td>90-94</td>
<td></td>
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<td>95-99</td>
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<td>100 and over</td>
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Gender

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<tr>
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<th>Number in house (Adults)</th>
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<tbody>
<tr>
<td>Male</td>
<td></td>
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<tr>
<td>Female</td>
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Occupation

<table>
<thead>
<tr>
<th>Adult</th>
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<tr>
<td>Adult 1:</td>
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<td>Adult 2:</td>
<td></td>
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<td>Adult 3:</td>
<td></td>
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<tr>
<td>Adult 4:</td>
<td></td>
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</tbody>
</table>

The number of years adults have lived within Australia:

<table>
<thead>
<tr>
<th>Person</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Person 1</td>
<td></td>
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<tr>
<td>Person 2</td>
<td></td>
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<tr>
<td>Person 3</td>
<td></td>
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<tr>
<td>Person 4</td>
<td></td>
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</table>

Origin of People

Quantity of persons

<table>
<thead>
<tr>
<th>Born in Australia?</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Born overseas?</td>
<td></td>
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</table>

Highest level of schooling completed

<table>
<thead>
<tr>
<th>Level</th>
<th>Quantity of persons obtaining this level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not go to school</td>
<td></td>
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<tr>
<td>Still at school</td>
<td></td>
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<tr>
<td>Year 8 or below</td>
<td></td>
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<tr>
<td>Year 9 or equivalent</td>
<td></td>
</tr>
<tr>
<td>Year 10 or equivalent</td>
<td></td>
</tr>
<tr>
<td>Year 11 or equivalent</td>
<td></td>
</tr>
<tr>
<td>Year 12 or equivalent</td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td></td>
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<tr>
<td>University or other</td>
<td></td>
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<tr>
<td>Tertiary</td>
<td></td>
</tr>
<tr>
<td>Masters Degree</td>
<td></td>
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<tr>
<td>PhD</td>
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</table>

Towards a Quality of Life Model for Sustainable Housing in South East Queensland

Survey Version [V2 – 04/02/2011]
Towards a Quality of Life Model for Sustainable Housing in South East Queensland

Estimated Weekly total household income - Gross (tick one)
- □ Negative/Nil income
- □ $1-$39
- □ $40-$79
- □ $80-$119
- □ $120-$159
- □ $160-$199
- □ $200-$299
- □ $300-$399
- □ $400-$499
- □ $500-$599
- □ $600-$699
- □ $700-$799
- □ $800-$999
- □ $1,000-$1,499
- □ $1,500-$1,999
- □ $2,000-$2,499
- □ $2,500-$2,999
- □ $3,000-$3,499
- □ $4,000 or more

Energy Rating of Design
NATHERS Energy Star rating of house (if known): ___________
Tool used (tick one): □ Accurate □ FirstRate □ BERS

Home Office
Is any part of the house used as a “home office” for business use?
If so, what is the size of this area _________ m²
How many hours per week on average over the last year was it occupied: _______ hrs.

Do you rent or own this home?
□ Rent □ Own

House Structure type
Separate house
Semi-detached, row or terrace house, townhouse etc. with:
One storey
Two or more storeys
Flat, unit or apartment:
In a one or two storey block
In a three storey block
In a four or more storey block
Attached to a house
Is this your primary or secondary home? ____________________________

Office Use Only
Processed by: ___________________________ Date: ___________________
# PART TWO: ENVIRONMENTAL ATTITUDES

This part of the survey asks about your opinion on environmental aspects. To answer, please tick the box beside each statement that most accurately represents the extent to which you AGREE or DISAGREE with the statement. You may choose a scale where (1) means that you STRONGLY DISAGREE with the statement and (7) means you STRONGLY AGREE.

<table>
<thead>
<tr>
<th>#</th>
<th>Items</th>
<th>STRONGLY DISAGREE</th>
<th>STRONGLY AGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I really like going on trips into the countryside, for example to forests or fields.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I find it more interesting in a shopping mall than out in the forest looking at the trees and birds.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I have a sense of well-being in the silence of nature.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Governments should control the rate at which raw materials are used to ensure that they last as long as possible.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I don't think people in developed societies are going to have to adopt a more conserving life-style in the future.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Controls should be placed on industry to protect the environment from pollution, even if it means things will cost more.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I would like to join and actively participate in an environmentalist group or already do.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>I would not donate money to support an environmental cause.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Environmental protection costs a lot of money. I am prepared to help out in fund-raising efforts.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>One of the most important reasons to keep lakes and rivers clean is so that people have a place to enjoy water sports.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Conservation is important even if it lowers peoples' standard of living.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Nature is important because of what it can contribute to the pleasure and welfare of humans.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Science and technology do as much environmental harm as good.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Modern science will not be able to solve our environmental problems.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Humans will eventually learn how to solve all environmental problems.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Humans are severely abusing the environment.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>The idea that the balance of nature is terribly delicate and easily upset is much too pessimistic.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>Items</td>
<td>STRONGLY DISAGREE</td>
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</tr>
<tr>
<td>----</td>
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</tr>
<tr>
<td>18</td>
<td>If things continue on their present course, we will soon experience a major ecological catastrophe.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>I prefer native plants in my garden.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Turning new unused land over to cultivation and agricultural development or housing development should be stopped.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>When nature is uncomfortable and inconvenient for humans we have every right to change and remake it to suit ourselves.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Whenever possible, I try to save and conserve natural resources.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>I cannot be bothered to save water or other natural resources.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>In my daily life I try to find ways to conserve water or power.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Human beings were created or evolved to dominate the rest of nature.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Plants and animals have as much right as humans to exist.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Plants and animals exist primarily to be used by humans.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Protecting peoples’ jobs is more important than protecting the environment.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Protecting the environment is more important than protecting current economic growth.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>The benefits of modern consumer products are more important than the pollution that results from their production and use.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>It makes me sad to see forests cleared for agriculture or development</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>The idea that nature is valuable for its own sake is naive and wrong.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Despite our special abilities humans are still subject to the laws of nature.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Families should be encouraged to limit themselves to two children or less.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>The government has no right to limit the number of children couples can have.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>We will be better off in the future if we are able to reduce the constantly increasing world population rate.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>