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Left in the dark: Prevalence of passive solar design in new urban developments in sub-tropical climates

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Author’s declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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***Left in the dark*: Prevalence of passive solar design in new urban developments in a sub-tropical climates**

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Energy energy demand for heating and cooling to maintain thermal comfort comprises approximately 40% of total energy use in a typical home. Since energy in our homes is largelhy fossil-derived, it is an area of policy focus due to its contribution to global climate change. This study investigates the prevalence of passive design as a strategy to reduce such thermal energy requirements of housing in Australia, in light of energy efficiency standards introduced into the building code. Development plans were examined, and it is concluded that orientation for optimum solar gain, is not a predominant passive design strategy in new residential housing, although it can potentially reduce thermal requirements by up to 28%, depending on building fabric. Interestingly, orientation may have less impact on thermal requirements with under projected climate change scenarios. These results have implications for decision making in the building energy efficiency field.

Keywords: buildings, climate change, energy efficiency, passive solar design

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1. INTRODUCTION

The built environment and its impact on broader sustainable development goals are well-cited in literature. Indeed, the energy consumption of the building sector is 25 to 40% of total consumption in developed countries, and as energy is largely fossil-fuel based, poses a significant contribution to greenhouse gas (GHG) emissions. By 2030, 80% of world's population is projected to live in cities, thus reducing energy consumption in the building sector is largely considered in tandem with sustainable development goals. Indeed, this was a topic of focus at the recent Rio+20 Summit.

The Intergovernmental Panel on Climate Change (IPPC) highlight opportunities for energy efficiencies in the built environment, citing strategies such as design for energy demand reduction and conversion from fossil-fuel energy platforms as means to reduce GHG emissions by 30% (IPCC 2007 as cited by Joelsson and Gustavsson 2009). This implies there is significant opportunity in the building sector to design buildings that reduce energy consumption during the course of their use (Pulselli et. al. 2004). Indeed, the literature on the topic suggests that a building's operation comprises a significant energy use (i.e. end-use energy) throughout the life cycle of a building, from raw materials extraction to demolition (Gustavsson and Joelsson 2010).

A building's design can significantly determine the thermal performance of a building, and hence energy efficiency. Thermal performance refers to how well a building is insulated from external weather conditions, thus how well it delivers comfortable temperature (termed “thermal comfort” in literature) to its occupants. Thermal comfort is the outcome of variables that may be independent or inter-related, e.g. building material, the volume of a room (Spanos et. al. 2005). However, as Spanos et. al. (2005) asserts, not all variables affect the thermal performance of the building in the same way, and that some variables may have greater influence than others. Prevailing climate and local topography affects the amount of available and exposure to sunshine at any given location, which adds further complexity to the issue (Lau et. al. 2007).

Passive solar design has been identified in literature as a means to enhance thermal performance and reduce energy consumption of a building. This is important given that heating and cooling requirements typically account for a large portion of overall energy consumption of a house (see Figure 1.1). This is achieved by utilising the basic elements of a building envelope (i.e. roof, floors, walls and windows) to collect and dissipate the solar energy provided by the sun to heat a building in winter, and by using these elements to reject heat in summer. By using the building design as a means to achieve thermal comfort, energy consumption via ‘active’ heating and cooling (i.e. air conditioning units, gas-fired boiler heating systems) may be reduced or even eliminated. In this manner, appropriate building envelopes for future housing developments have the potential improve the energy efficiency and environmental sustainability of building stock.

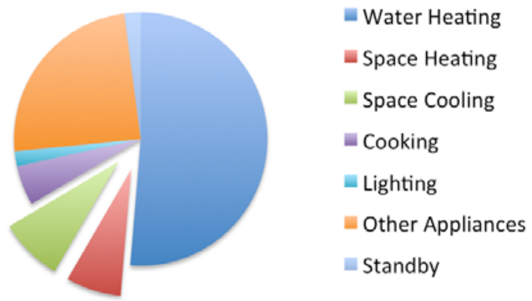

Figure 1.1 Heating and cooling energy requirements, in relation to overall energy consumption of a typical home (Source: Saman 2013)

2. BACKGROUND

Passive solar design is identified in literature as a means to reduce end-use energy consumption in new residential buildings. Passive solar design (PSD) is described as utilising energy from the sun whilst taking into consideration local climate characteristics and building materials in order to maintain thermally comfortable conditions in a building (Rabah 2005). PSD takes into account of key building parameters such as building orientation, thermal mass, plan shape and proportions, facade glazing design and shading provided by surrounding buildings and/or objects (Aksoy and Inalli 2006; Numan et. al. 1999). For example, glazing design should incorporate size, location, and thermal performance of frames and glazing, though such considerations should be balanced with natural ventilation. Appropriate insulation, sealing and draught-proofing of the building envelope are other PSD strategies cited in literature. Haase and Amato (2009) propose that in most climates, provision of thermal comfort via passive means will reduce, potentially eliminate, active control requirements (i.e. heating and cooling by mechanical means such as fans, air conditioning units).

PSD is not a new concept, indeed it was practised by the ancient Greeks (Miller et. al. 2012), though its prevalence in the current building industry is not well understood. Kruzner et. al. (2013) attempted a systematic analysis of the prevalence of PSD in existing homes in the United States (U.S.), examining orientation, roof colour[1] and

[1] The darker the roof colour, the higher the degree of radiative heat transfer. Thus the interior of the building would theoretically be warmer than if the house had a lighter roof colour, all else being equal.

degree of shading, and concluded that PSD has not been a major consideration in the design of existing home in the U.S. Similarly, the Australian housing market does not exhibit heavy emphasis on PSD. Housing designs and constructions have not considered energy efficiency as a high priority due to the abundance of cheap energy; rather, aesthetics and larger built area at minimum construction costs have been two key attributes used for marketing both new and existing houses (Saman 2013). Historically, low energy prices have been a common denominator between the U.S. and Australia, which translates to relatively low operational energy costs for residents. The lower the cost savings, the lower the motivation to implement PSD strategies (Kruzner et. al. 2013), thus, it is hypothesized that PSD have not been taken into consideration in the existing residential building stock in Australia.

The most important decisions that affects a building’s end-use energy consumption can be made in the early design stages, by the architect or building designer (Schlueter and Thesseling 2009). However, analysis of various PSD parameters during the design stage incurs additional design time and hence costs (Spanos et. al. 2005). Such additional costs are often cited as an explanation for building industry’s resistance to change and innovation (Ryghaug and Sørensen 2009). The reported cost of implementing higher energy efficiency standards are typically widely disparate, although such costs (e.g. of acquiring new expertise, training, etc.) are generally not well understood due to the fragmented structure of the industry.

Amongst the PSD principles (see Balcomb et. al. 1977; Hoffman 1983; Givoni 1991) window and building orientation are generally regarded as the most cost-effective means of reducing end-use energy consumption. This is because it is the most easily addressed aspect of PSD and relatively simple and inexpensive to accomplish if planned at early stages of the design process (Andersson et. al. 1985). Buildings and windows that are not oriented toward the winter sun /facing the equator (i.e. without a northern orientation in the southern hemisphere, and a southern orientation in the northern hemisphere [2]) require more energy for space heating and cooling than comparable buildings with appropriate orientation. This is due to reduced availability of daylight, and hence the heating benefits from solar gain in winter is reduced, whilst in warmer climates, higher cooling loads may result in summer from solar gain (Morrissey et. al. 2011; Rabah 2005).

The literature on PSD emphasises the importance of orienting glazing for optimal solar gain, however this must be in balance with glazing area such that heat loss does not drastically impact on internal thermal performance (Spanos et. al. 2005). Location of windows are thus influential; for example in sub-tropical climates, where space conditioning requirements tend to be dominated by cooling needs during summer, designing windows to reduce the exposure of living room windows to the midday sun will reduce mechanical or 'active' cooling demand. Moreover, Morrissey et. al. (2011) argues appropriate orientation can create potential for additional savings from more sophisticated passive solar techniques (e.g. skylights. See Gacia-Hansen et. al. 2002; Omer 2008).

Morrissey et. al. (2011) propose two ways to ensure optimal orientation; (1) analysing the various parameters to ensure optimal design (insulation, etc.) on a building-by-building basis; or (2) developing adaptable designs that can perform well across a

[2] The sun crosses the southern sky by day in the northern hemisphere, and vice versa.

range of orientations. The former approach entails cost implications as anecdotally used in the volume build industry, as standard specifications and layouts of housing attain economies of scale for building contractors.

Morrissey et. al. (2011) conducted a study comparing standard volume-build house designs and their energy performance across the eight (8) orientations (North, North-East, East, etc.), and concluded that more energy efficient houses are less susceptible to effects of orientation, for a given floor area. Moreover, it was found that floor area was the most influential factor in terms of the variability in energy performance across orientation; as floor area increases, the more orientation plays a role in energy performance of larger houses than of smaller houses. This suggests that larger houses (defined as over 250 square metres in the study) may be more disproportionately more expensive to operate. It also suggests that smaller houses can be subject to different orientations without compromising on energy performance. Nonetheless, Morrissey et. al. (2011) conclude that orientation considerations are an important first step in the integration of PSD principles at the building and development stages, as once implemented, its effects are harder to reverse relative to other PSD measures such as insulation.

Kruzner et. al (2013) investigated the prevalence of PSD in the U.S., however investigated orientations via satellite imagery (i.e. Google Earth). However, literature highlights the difference in what is deemed a comfortable temperature and resultant occupant behaviour between living areas versus bedrooms. For example, in bedrooms the temperature range that occupants can tolerate is higher, as occupants can simply pull bedsheets or doona covers over themselves if temperature drops, whereas the response may be different in living areas (e.g. opening a window, turning on the heater). Such manual response and occupant behaviour is termed ‘adaptive thermal comfort’ in literature (Miller et. al. 2012), which can alter the heating and cooling requirements of a building. Thus Kruzner et. al.’s (2013) study, by regarding north-east orientation as optimum passive solar design, somewhat assumes a north-facing living area/s (used for most part of the day and therefore requires maximises solar gain in winter). However, overhead satellite imagery does not reveal such details, and if living areas were not indeed north-facing, optimal passive solar design has not been achieved as higher heating loads than otherwise required may result due to differing requirements for thermal comfort between living areas and bedrooms. The shortcoming of the approach toward the above study is somewhat addressed by Peterkin (2009), who explicitly investigates the placement and orientation of living areas and bedrooms within a house (e.g. living areas should face true north) and associated adaptive thermal comfort. Peterkin’s (2009) is an ex-ante study to quantify effect of orientation on the thermal energy needs of a house. However, no ex-post study has been conducted to date to investigate is there has been optimal orientation of living areas and bedrooms in the Australian residential building stock, let alone since the energy efficiency standards were introduced into the building code (described later in this section).

2.1 AUSTRALIAN CONTEXT

The energy consumption of commercial and residential buildings in Australia accounts for approximately 20 per cent of Australia’s greenhouse gas emissions. In the residential building sector, space heating and cooling comprise 41% of residential energy demand (see Figure 1.1), and is responsible for 11% of Australia's national GHG emissions (ABS 2010; Wilkenfeld G. Associates. 2002). The energy consumption of the residential sector is projected to increase by 56% over the period 1990 to 2020 (DEWHA 2008). According to climate change projections derived from simulations performed for the Intergovernmental Panel on Climate Change 4th assessment report, Australia must adapt to increasing frequency of heat waves. Moreover, the number of days over 35°C is predicted to increase by 50% by 2030, and almost doubling by 2050 (Suppiah 2007), thus implying a significant increase in cooling requirements. It is thus imperative to target energy use in the residential sector to simulaneously address current and projected climate change. Space conditioning (particularly cooling) is perhaps the most relevant and direct area to focus on, given Australia's current reliance on fossil-fuel based and GHG-emissions intensive energy sources, as well as in the foreseable future.

Government initiatives have been implemented in order to incentivise households to use energy more efficiently or install renewable energy systems (e.g. solar panels) in order to limit energy use and consequent GHG emissions. Some examples of such national and state-level government programs targeting new homes, as well as Australia's existing eight (8) million dwellings are provided by Saman (2013), and include:

- Rebates (approximately USD$1000) for households replacing electrical resistance heaters with solar hot water systems;
- Free energy home assessments; and

- Free roof thermal insulation to all uninsulated Australian homes[3]

Peterkin (2009) purports that although PSD is a ‘cost effective’ and relatively easy way of achieving improved energy performance, it is not widely adopted in residential building practice in Australia, with only anecdotal evidence such as abovementioned government initiatives to date. The main driver for increased energy efficiency in general (the objective of PSD) in new buildings is legislation, and primarily through binding building standards (Clarke et. al. 2008). In Australia, where this study was undertaken, the Building Code of Australia (BCA) provides such energy efficiency regulations. The evolution of these regulations will be discussed in the following section.

The Australian Government announced in July 2000 that all State and Territory Governments had agreed to introduce mandatory energy efficiency standards into the Building Code of Australia (BCA) in order to reduce GHG emissions associated with building operation. Energy efficiency measures for residential buildings were subsequently introduced into BCA on 1 January 2003. In 2006, energy performance requirements were enforced via a “5 star or equivalent” requirement. In 2009, the Council of Australian Governments (COAG) announced that it would ask the Australian Building Codes Broad to increase this stringency to “6 star or equivalent”. Notably, this energy efficiency rating applies to the building envelope only, i.e. energy requirements after taking into account of solar gains and losses via building

[3] The Home Insulation Program, which installed insulation in over one (1) million homes, was discontinued within a year due to fire and safety risks associated with improper installation of insulation material in older roofs

elements (roofs, floors, walls and windows), and not by heat given off by lighting, plug-in appliances, etc.

However, the introduction of the ‘5 star’ regulations was not implemented without difficulty; as in the case of the UK and Norway (see Ryghaug and Sørensen 2009) there was controversy over the stringency of energy efficiency requirements through such regulation. There was also debate over whether regulations set standards too high (or too low[4]); what economic costs may be involved; and if tools, timescales and institutional arrangements were appropriate (Morrissey et. al. 2011; Horne et. al. 2007). Regulations are criticised by many designers and builders as an additional burden (DavidGann et. al. 1998) due to cost implications as discussed in the previous section.

It has been demonstrated that applying some PSD principles such as good orientation, location on site, and landscaping changes may potentially reduce the energy requirements of a typical dwelling by 20 per cent (Spanos et. al. 2005). Given the potential of PSD to reduce energy requirements, it is interesting to note that no specific research has been conducted to investigate whether PSD principles have been exploited fully in new residential buildings, particularly since the energy efficiency standards were introduced into the BCA and increased in stringency over the past decade.

PSD contribute toward achieving a fully passive house, which according to the International Passive House Association (2012), is defined a house that does not

[4] One study benchmarking the 5 star regulations against standards internationally, showed that the stringency of the Australian standards was relatively low (Horne and Hayles 2008).

require conventional heating and cooling units at all. Research on passive housing internationally to date has tended to focus on homes on cool, moderate climates of northern Europe, and hence heating-dominated contexts. Indeed, the 'Passive House Standard' was developed in Germany in the early 1990s, though experience has proven it works well in a wide variety of climates - both hot and cold, mild and extreme. Passive housing principles encompasses PSD principles as well as, for example, ancillary heat recovery systems. Germany and Belgium already stipulate the Passive House Standard in their building regulations. Over the last two decades, the Passive House Standard has gained rapidly in popularity, with more than 37,000 homes[5] built and certified to the Standard worldwide (IPHA 2012), though a search of the International Passive House Association database reveals there are none to date in Australia, further supporting the hypothesis that PSD have not been taken into consideration in the residential building stock in Australia.

There is a trend toward smaller households and bigger homes[6], with mechanical active heating and cooling regarded as "necessity" (Morrissey et. al. 2011). Indeed, Peterkin (2009) notes "it appears that domestic air conditioning may be rapidly moving from a desirable to an essential commodity, [for example] 69% of Perth homes have some form of air conditioning compared with 35% in 1994." Additionally, over three quarters of Australian dwellings had one or more space heaters and two thirds had space coolers in 2008 (ABS 2008). Kruzner et. al. (2013) argues that "the widespread adoption of air-conditioning and other strategies to mechanically control the indoor environment mean that passive design is not

5 As at 2012.

6 Australian Bureau of Statistics figures show that average dwelling size rose from 2.9 rooms per dwelling in 1994-1995 to 3.0 in 2003-2004, a trend broadly mirrored in other OECD countries. During the same period, household sizes have decreased from an average of 2.7 to 2.5 people per household (Gustavsson and Joelsson 2010)

necessarily a requirement for occupant comfort. Rather than optimize the passive design of a home in a hot climate, for example, a designer can just specify a more powerful air conditioning unit." Such research outcomes suggest that the BCA energy efficiency standard does not encourage passive housing design.

Thermal performance of housing across a range of different building fabrics (e.g. cladding materials, flooring, etc.) has been highlighted as a research gap (e.g. Morrissey et. al. 2011). Indeed, most studies that investigated thermal performance of residential homes considers brick veneer external walls. In the sub-tropical climate zone of Brisbane, Australia, the external walls of houses consist of materials of highly variable thermal mass (i.e. fibro cement, timber and brick). Brisbane poses a potentially revealing case study of material and orientation effects on heating/cooling requirements of a house.

Brisbane, the capital of the state of Queensland, is the third-most populous city in Australia (Australian Bureau of Statistics 2011). It is located in a sub-tropical region, experiencing hot humid summers with high rainfalls, and mild dry winters with low rainfalls. Brisbane's climate is classified as 'Warm humid summer, mild winter', zone 2 within the Building Code of Australia climate classifications.

The climate is comparable in terms of seasonal and diurnal (fluctuations throughout the day) temperature and humidity to parts of the Mediterranean in the northern hemisphere and South America in the southern hemisphere. The technical manual published by the Australian Government suggests lightweight construction as a key design response to Brisbane's climate, however trends suggest brick veneer maintaining and even growing in popularity over the years according to Australian Bureau of Statistics (2010). The growing popularity of brick veneer homes is counter to this advice, further warranting the investigation of material effect on heating/cooling requirements of a house.

Brisbane has a current population of 1.86 million and an area of over 2000 square kilometers (Queensland Government 2011), with an overall density of 340 people per square kilometer (ABS 2011b), its most densely populated areas in the inner-city regions with its central business district about 20km inland from the coast. Brisbane has experienced an annual population growth rate of 2.3% (2004-2009 statistics) (ABS 2011a).

The 6-star minimum energy equivalence requirement for new housing was introduced on 1 May 2010 in Queensland. Compliance is met by satisfying the 'Deemed to Satisfy' (DTS) provisions or modelling verification by using house energy rating software approved under the National House Energy Rating Scheme (NatHERS), described in the Methodology section.

Climate change impact based on both best (i.e. stabilised GHG emissions[7]) and worse case scenarios (i.e. largely fossil-fuel based energy supply trajectory) are predicted to increase Australia's cooling needs. Wang et al. (2010) investigated the potential impact of climate change on the heating and cooling energy requirements of residential houses in five climates zones in Australia varying from cold to hot-humid. The study postulates that for housing in temperate climate regions with balanced

[7] To 550 ppm stabilisation emission scenarios.

heating and cooling needs, the increase in the total heating and cooling energy requirement is up to 120% and 530% for a newly-built house [8] if the global temperature increases 2°C and 5°C respectively. This suggests that the increase in heating and cooling energy requirements for existing residential building stock may be even higher due to the poor thermal performance of the existing housing stock (Morrissey et. al. 2011).

Hence, investigating the prevalence of PSD in housing stock built since the BCA energy efficiency standards were introduced is necessary to determine its potential to help future proof new developments to climate change. Moreover, with fuel poverty recently reported as an emerging social issue, resulting from rising energy prices. This is due to growing peak demand and subsequent network investments required to meet this demand, translating to higher prices for end consumers as approximately 50% of the 49% of residential electricity charges are associated with network costs (Miller et. al. 2012).

This current study attempts to fulfill research gaps determined through the review of literature regarding energy efficiency through passive solar design of residential buildings. This study investigates end-use energy consumption in the residential sector, taking Brisbane as a case study. Given the reluctance of the building industry to incorporate PSD into new residential buildings, it is especially important to consider low-cost yet cost-effective PSD principle. The low-cost variable identified as being the significant in terms of building thermal performance is orientation of house designs in order to optimise passive solar performance. Orientation refers to the axis

[8] Housing built since 2003 are subject to minimum energy effiency standards.

along which the house is elongated. One technique for PSD includes orienting windows toward the equator, thus elongating houses on the east–west axis means that a greater area available for south-facing windows, and thus greater potential for passive solar heating than a north-south axis (Kruzner et. al. 2012). This PSD principle that can be easily accommodated during the design stage, to enable relatively adaptable plans to suit the business models of building developers.

This current study is an ex-post study on the mandatory energy efficiency standards introduced into the Building Code of Australia and its motivation for PSD, in particular optimum orientation, of new residential buildings. Australia is characterised by fossil-fuel based energy sources in the forseeable future, with climate change projections resulting in increased cooling requirements. Social demographic trends tend toward smaller households yet bigger homes that feature mechanical heating and cooling as standard. Meanwhile, fuel poverty is a growing problem on the other side of the spectrum. As such, this study is also an ex-ante investigation on the potential of orientation across different building materials on end-use thermal energy consumption in the residential sector. This study uses Brisbane as a case study due to the different construction materials used in its current housing stock.

3. RESEARCH AIM AND OBJECTIVES

This study aims to improve understanding of current passive solar design implementation in Australia in order to identify ways to make implementation more widespread due to its potentially significant contribution toward reducing energy consumption and associated GHG emissions. This study aims to assess if passive solar design principles are being exploited in new residential buildings, is also important given the social trends such as bigger homes mentioned in the previous section, that can potentially outweigh any reductions in overall energy consumption.

In response to this need, the objective of this research is to examine homes built in Brisbane since energy efficiency requirements were introduced into BCA (i.e. since 2003) for trends that are consistent with low-cost strategies for PSD, namely orientation of houses for optimum passive solar thermal performance. This study attempts to determine the prevalence and potential of passive solar design in new residential buildings in Brisbane, Australia, in light of the energy efficiency regulation introduced into the Building Code of Australia in 2003 that has increased in stringency over the ensuing decade. By undertaking a systematic analysis of the new housing market in Brisbane, Australia, this study is a first step toward understanding the prevalence of passive housing strategies in the Australian housing sector, which is currently not well understood and where there has been only anecdotal evidence to date. This study seeks to add to the existing body of literature regarding role of orientation on thermal performance (end-use or operational energy consumption) of residential buildings.

This study will be guided by the following research questions:

1. What is the prevalence of orientation considerations in new residential development in Brisbane since the BCA energy efficiency standards were introduced in 2003?
2. What is the magnitude of potential energy savings from future new residential development from appropriate orientation?
3. What challenges and opportunities exist in the residential sector for passive solar design?

3.1 INTENDED AUDIENCE

The outcomes of this research is anticipated to provide evidence to support decision makers in finding more environmentally sustainable energy solutions in the residential housing sector, particularly policy development relating to building energy efficiency and urban planning. The focus on low-cost passive solar design options can also be used by building developers to meet energy efficiency regulations.

3.2 LIMITATIONS OF RESEARCH

This study focuses on end-use (operational) heating and cooling energy requirements of new residential houses. Embodied energy is excluded from this study, due to the fact that operational energy tend to dominate energy balance (Gustavsson and

Joelsson 2010). Detached housing are characteristic of a typical Australian home (Saman 2013), hence are the subject of analysis. Notwithstanding, orientation is also of significance on energy efficiency at the development scale, as the way a block of houses are oriented can affect the ‘solar envelope’, defined as “the physical boundaries of surrounding properties and the period of their assured access to sunshine” (Morrissey et. al. 2011). This limitation is somewhat overcome by the nature of plans investigated (i.e. on one-by-one and not master-planned development basis). Effects of housing density are neglected in this analysis, though with urban sprawl being a characteristic of urban development in Australia, its impact on result is assumed negligible. The effects of local topography and other site constraints, such as overshadowing, which would in reality limit scope of PSD, are also neglected it this study.

4. METHODOLOGY

The methodology employed in this study involves statistical data collection and analysis, and semi-structured interviews with key actors in the building industry. House plans were sourced from the Brisbane City Council's [9] Planning and Development website to determine if PSD principles had been a factor in new residential housing in Brisbane since the energy efficiency regulations were introduced into the Buildings Code of Australia in 2003. Only approved development applications since 2004 could be obtained online, however this is assumed to have negligible effect on the results due to the relatively long time span being investigated (a period of nine (9) years), and a time lag for regulations to take effect.

A total of 1463 approved development applications were recorded between 1 January 2004 to 1 January 2013 for of new detached residential housing. This list was entered into a Microsoft Excel spreadsheet sorted by date, and each record assigned a numerical value, starting from 1 and ending in 1463. It was found that development approvals dropped in 2009-2010 (refer Figure 4.1), most likely due to a combination of high interest rates and the aftermath of the Global Financial Crisis. However, as such factors relate to affordability of housing purchase as opposed to affordability of housing operation, decision-making regarding the actual operation of the house (and hence running costs to operate heating and cooling equipment) is not impacted. As such, the drop in development approvals does not have a strong link to motivations

[9] Local government authority for Brisbane

for reducing operational energy/increasing energy efficiency, and this observation is not deemed important to the outcomes of this study.

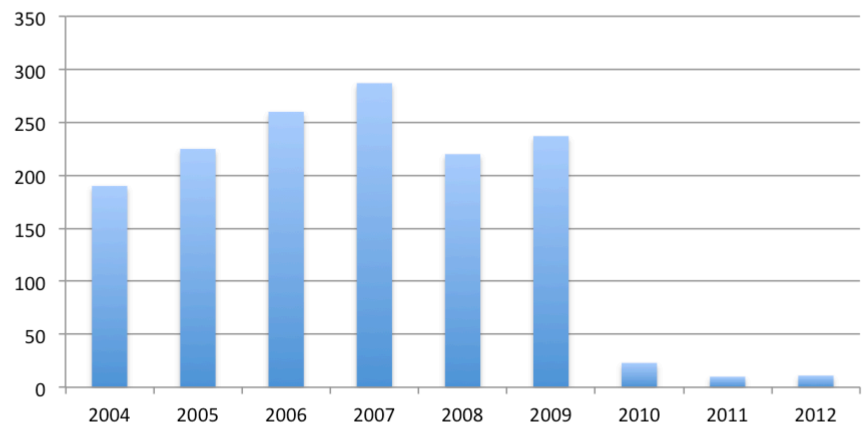

Figure 4.1 Number of development approvals in Brisbane 2004-2012

In order to calculate a statistically robust sample size that is representative of new residential housing in Brisbane, a confidence level of 95% and confidence interval of ± 5% was used. The sample size is determined using the following formula:

$$n = \frac{Z^2 p(1-p)}{D^2}$$

where n is the sample size needed, Z is the z-score from the normal distribution for the confidence level 95% (1.96), p is the proportion of population estimated (0.5), and D is the confidence interval as a percent (0.05). The sample size of 385 calculated is then adjusted for the small population based on the following formula:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

where n_0 is the original sample size calculated (385). The revised required sample size is 304, i.e. at least 304 records were needed for the random sample.

A sample of 310 plans was thus selected for analysis. In order to choose which 310 plans to analyse, the Microsoft Excel "random" function was used to generate 310 random numbers between 1 to 1463. Its corresponding development approval record was noted, and the plan downloaded for review. For each 310 plans, orientation (the key low-cost PSD variable as identified in Chapter 2) of the home's longitudinal axis (refer Figures 4.2 and 4.3 depicting how orientation was determined in this study) and its main living areas (e.g. living room, kitchen) were recorded in a spreadsheet. The possible orientations are as per the eight (8) cardinal directions. A sample of detached, single and double story residential dwellings of various sizes was analysed, as well as houses relocated on the same block of land as it was deemed an opportunity to possibly re-orient buildings and/or living zones to be exploit PSD principles.

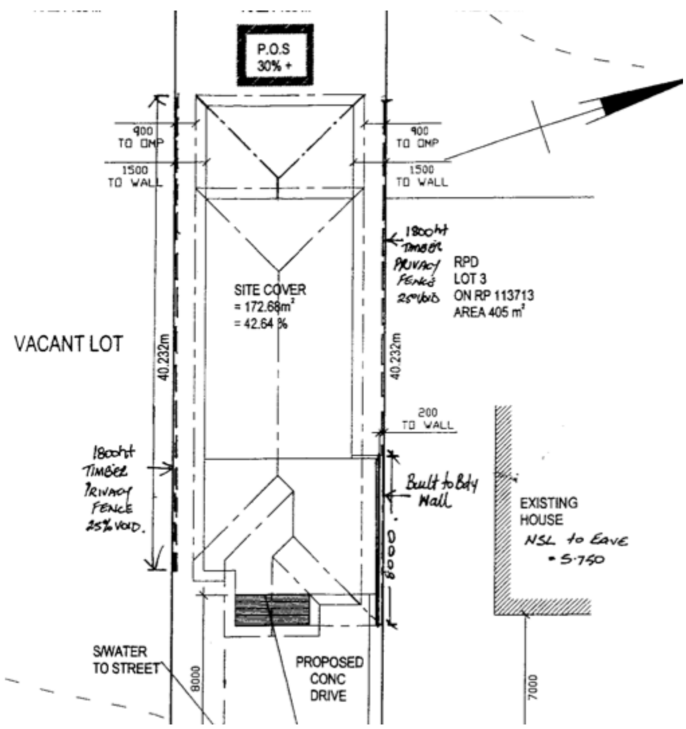

Figure 4.2 Example of house elongated along the east-west axis (arrow points to north)

Hypothesis testing was conducted with the collected data to determine if there was statistically significant number of homes incorporating PSD principles of: overall house orientation toward the equator (i.e. north) to maximise solar heat gain, orientation of living areas oriented to the north to maximise solar gain in winter. A tolerance of 15 degrees to the west of north and 20 degrees to the east is deemed to be generally north, consistent with approach taken by Peterkin (2009).

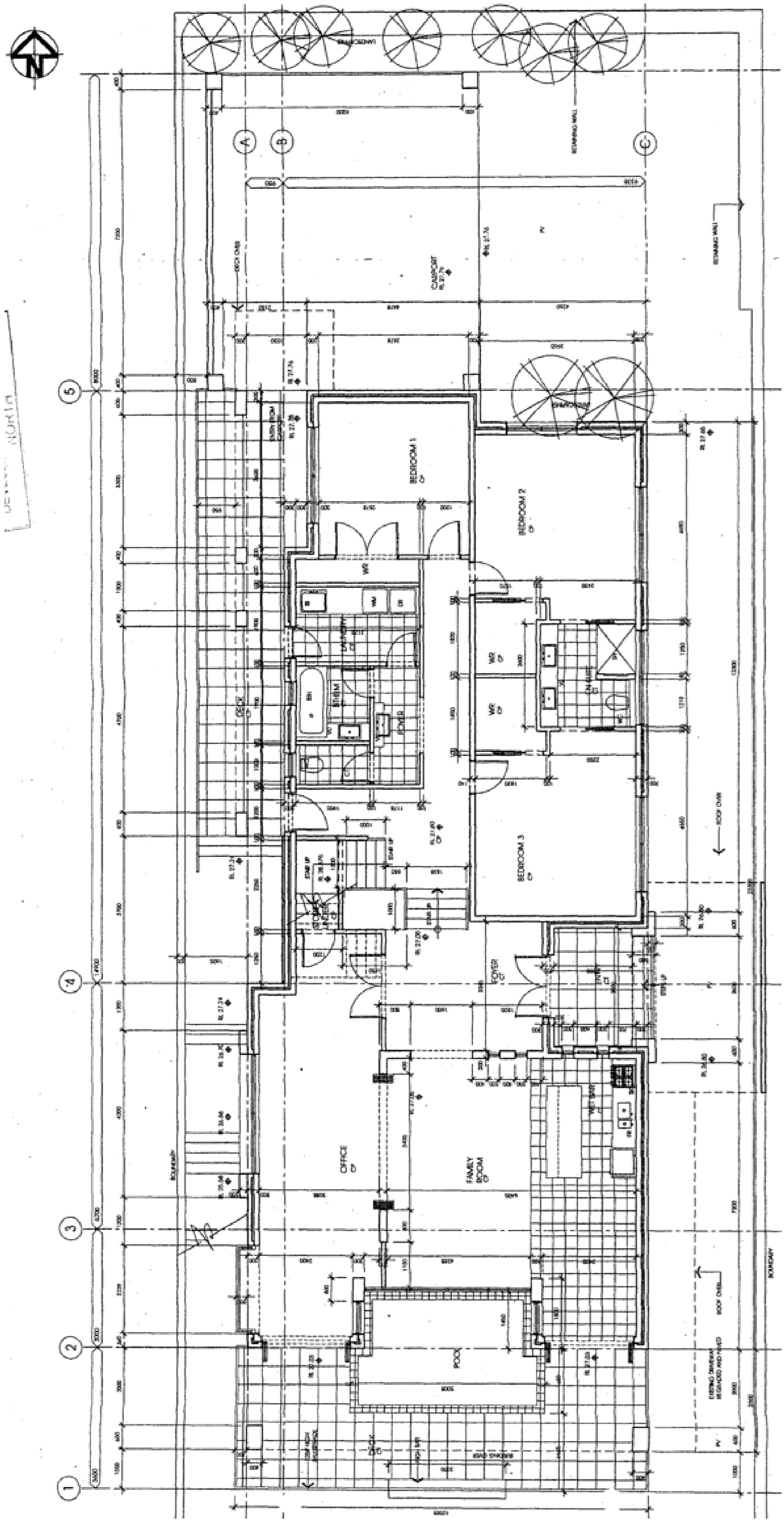

Figure 4.3 Example of house with living area oriented toward the south (arrow points to north)

To examine the effects of orientation on the thermal performance of residential buildings in Brisbane, computer simulations were used. Energy efficiency measures have complex inter-related effects on residential end-use energy consumption and associated GHG emissions. A building envelope's thermal performance is the result of the complex interaction and "dynamic function of orientation, building geometry, glazing ratio, heat-flow path, inter-zone heat transfer mechanisms[10] and thermal mass properties of materials[11]" (Morrissey et. al. 2011). The use of computer models and simulations rather than costly prototypes experiments to evaluate these effects are advantageous, with numerous applied examples of energy modelling approaches for residential buildings in literature.

In this study, the National House Energy Rating (NatHERS) software called AccuRate Sustainability Tool v2.02.13 was used. AccuRate[12] was developed by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and estimates the total energy requirement in terms of heating and cooling loads, as calculated hourly over a typical year using typical weather data appropriate for the location. Standardised occupant behaviour and principles of adaptive thermal comfort is used in the program.

The program assigns a house energy rating (on a scale of 1 to 10 stars) based on the building envelope's thermal performance, which is currently legislated. Dwellings with more stars require less active heating or cooling to deliver thermal comfort to its

[10] For example, radiative heat transfer through floors, or convection through ventilation air flows between rooms, partitions/walls

[11] For example, concrete has a higher thermal mass than timber, hence expected to have better heat conducting ability.

[12] AccuRate has been validated using BESTEST protocol developed by the International Energy Agency (CSIRO 2011).

occupants, and a 10 star home theoretically does not require any active heating and cooling measures. This rating is based on calculated annual heating and cooling energy requirements after taking into account of the building envelope's ability to maintain heat required in winter and extract heat in summer. It does not measure consumption per se, i.e. the efficiency of heating and cooling equipment itself is not taken into account. It does not consider heat given off by lighting or appliances.

A house plan was modelled in AccuRate to investigate building orientation and material effects on thermal energy loads. This plan was based on a typical Australian home, which is detached, 200 square metres in plan area and has 3 to 4 bedrooms, and has single glazed, mostly unshaded windows (Saman 2013). Building envelope parameters were adjusted to attain the 6 star minimum energy rating required by the BCA energy efficiency regulations. Roof and wall insulation is becoming the norm due to building regulations. Two (2) prototypes were modelled based on this plan, such that one had external wall made of timber and the other of brick veneer construction, the common construction types for 65.8% of dwellings in Brisbane. Both prototypes modelled were single story dwellings.

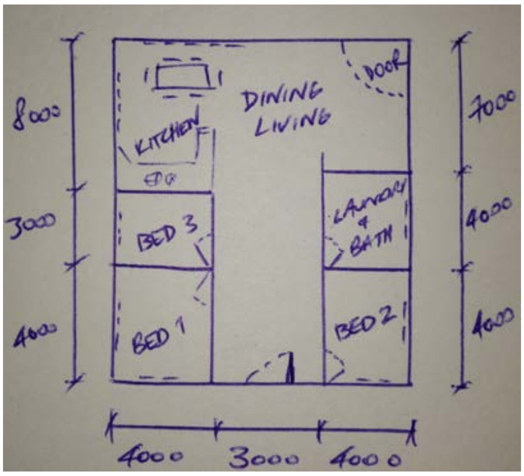

Figure 4.4 Schematic of the modelled house plan (all dimensions in millimetres). Not to scale)

When changing the orientation the house as a whole was rotated such that glazing areas were not adjusted, reflecting the assumption that volume builders desire minimal adjustment to “stock plans” in actual construction, as per Morrissey et. al. (2011). In order to investigate effect of climate change on the new residential housing, the climate zone immediately north of the current one was used, as a proxy for an increase in temperature due to climate change (the average temperature increase is 2°C, which closely matches IPCC climate change projection scenarios for 450ppm).

Table 4.1 Specification of typical house modelled (external wall material varied using timber 150mm mountain ash and brick veneer with 40mm air gap and plasterboard on studs)

Parameter	Specification
Floor area/conditioned floor area	$200m^2/124m^2$
No. of floors	1
No. of bedrooms	3
Roof/ceiling insulation/construction	R3.0 bulk insulation/tiles of medium roof colour[13]
External wall insulation/construction	R3.0 bulk insulation/450mm wide eaves
Floors	Standard concrete slab on ground with carpet and felt underlay, tiles in kitchen and living areas
Windows	Single glazed 4 mm clear aluminium frame
Doors	Solid timber

13 Roof colour is not a significant consideration at the levels of ceiling insulation required by the BCA (Peterkin 2009)

5. FINDINGS AND ANALYSIS

Appendix A provides an excerpt of the spreadsheet recording the orientation of living areas. In order to address Research Question 1 “What is the prevalence of orientation considerations in new residential development in Brisbane since the BCA energy efficiency standards were introduced in 2003?”, based on effective passive design strategies cited in literature, hypothesis testing was undertaken using the following:

H_0: The majority of houses are elongated along the east-west axis

H_1: The majority of houses are no elongated along the east-west axis

P_0: 0.5

α: 0.05

H_0: The majority of houses have living areas oriented to the north

H_1: The majority of houses do not have living areas oriented to the north

P_0: 0.5

α: 0.05

At a significance level of 0.05, it was found that there no statistical evidence to support the hypothesis that the majority of houses are elongated along the east-west axis, and there is no statistically significant trend of houses having living areas oriented to the north. To investigate if there is trends at all regarding longitudinal orientation of houses and living area orientation, hypothesis testing was undertaken for all the other cardinal directions. Likewise, there is no trends in any direction, suggesting that there is no real consideration of any orientation in the design of new houses.

In order to address Research Question 2 “What is the magnitude of potential energy savings from future new residential development from appropriate orientation?”, computer modelling was conducted using AccuRate as discussed in Chapter 4. Figure 5.1. show energy loads for the two (2) prototype designs across the 8 orientations modelled for the timber and brick prototypes, for the current climate characteristics.

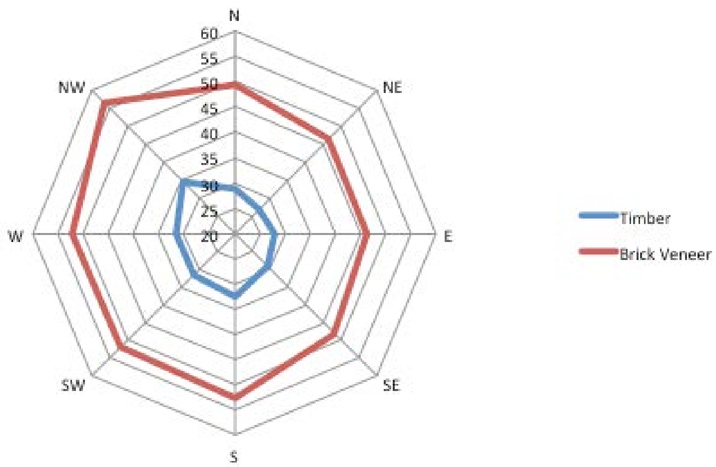

Figure 5.1 Total heating and cooling requirements (in MJ/m2/year?) across eight orientations of timber and brick veneer homes

As can be seen, the total heating and cooling loads of the brick veneer houses are almost double that of timber houses across all orientations, which proportionately (and counter intuitively) more heating than cooling required (up to 50% more) (refer Figure 5.2). However, for both timber and brick houses oriented to the north-west results in the largest thermal energy loads. This may in part explain why elongation along the east-west is not a common orientation. For houses with timber external walls, savings of up to 28% can be realised with the optimum orientation, and 22% for brick external walls.

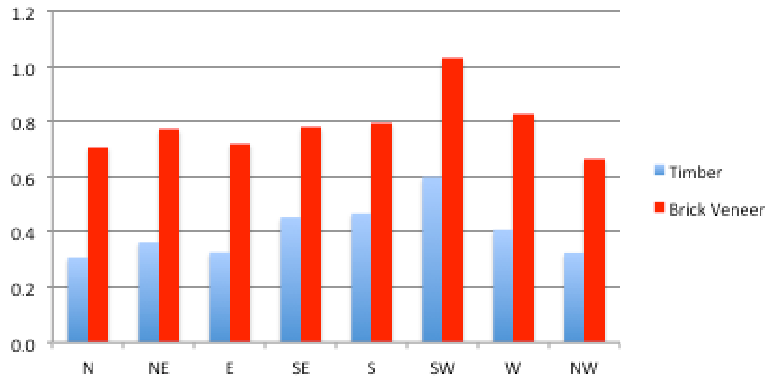

Figure 5.2 Ratio of heating to cooling requirements across eight orientations of timber and brick veneer homes

The trends are very similar for the projected climate change scenario. Figure 5.3 shows energy loads for the two (2) prototype designs across the 8 orientations modelled for the timber and brick prototypes, for the projected climate change scenarios.

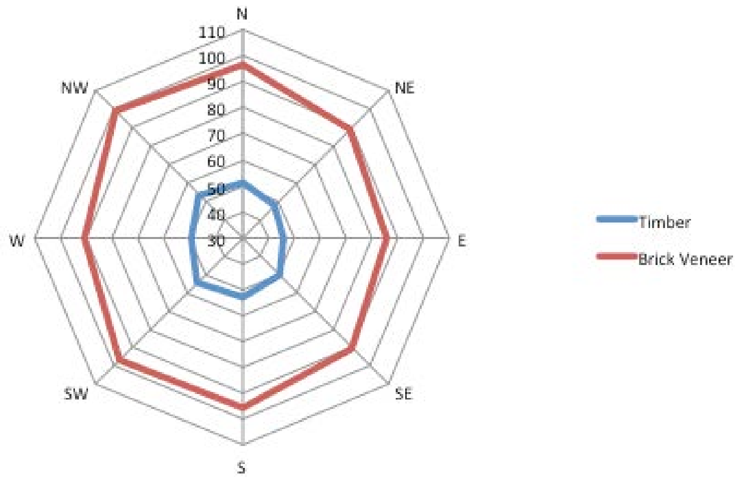

Figure 5.3 Total heating and cooling requirements (in MJ/m2) across eight orientations of timber and brick veneer homes, projected climate change scenario

As can be seen, the total heating and cooling loads of the brick veneer houses are almost double that of timber houses across all orientations, which proportionately (and counter intuitively) more heating than cooling required (up to 50% more) (refer Figure 5.4). However, for both timber and brick houses oriented to the north-west results in the largest thermal energy loads. This, once again, may in part explain why elongation along the east-west is not a common orientation. However, in contrast to the current scenario, savings of up to 10% can be realised with the optimum orientation for both timber and brick external walls.

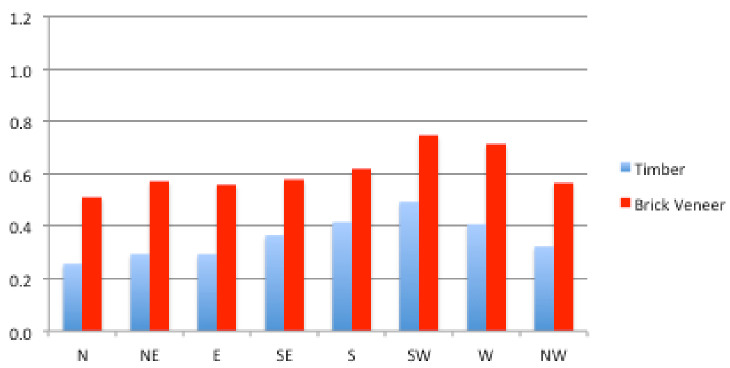

Figure 5.4 Ratio of heating to cooling requirements across eight orientations of timber and brick veneer homes, projected climate change scenario

To investigate the sensitivity to climate change relationships further, current and projected climate change scenario were superimposed for each prototype (refer Figure 5.5). It can be seen that thermal energy loads almost doubles for both timber and brick houses across all orientations. That is, the reduction in heating loads is outweighed by the increase in cooling loads required regardless of construction material of external walls. Thus, with increasing temperatures associated with climate change, the total thermal performance (star rating) decreases for houses regardless of material (timber or brick). These results are similar to Peterkin (2009). However, scenario modelling demonstrated that the effects of orientation on total thermal loads are about 10% for both timber and brick. In other words, orientation may matter relatively less with climate change.

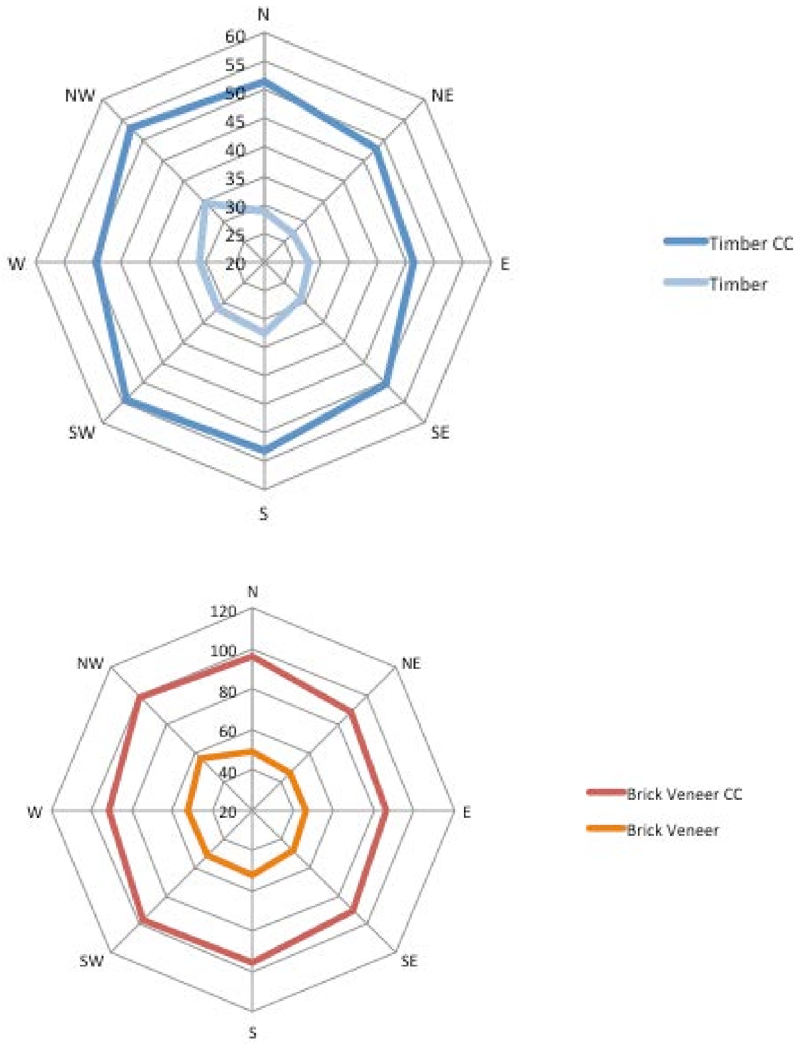

Figure 5.5 Total heating and cooling requirements (in MJ/m2) across eight orientations of timber and brick veneer homes, comparing current and projected climate change scenario (denoted by "CC")

In order to address Research Question 3: "What challenges and opportunities exist in the residential sector for passive solar design?" semi-structured phone interviews posing the above question were conducted with relevant market actors. Snowballing approach was used to determine PSD principles can be further exploited to attain higher building energy efficiencies. One academic cited opportunity for star rating to increase market value, as anecdotal evidence of increased resale value in the Australian Capital Territory due to mandatory residential disclosure. Importance of influencing consumer perceptions are highlighted by a representative of the PassiveHouse Association. However, there is still a perception that passive housing automatically implies additional cost by housing industry associations. Despite presenting some preliminary results of this study of 22 to 28% energy savings with appropriate orientation for new houses in Brisbane, the general reaction was that consumers do not demand it and hence it is not a priority for the housing industry. To gain a consumers' perspective, real estate agencies were approached and asked if consumers place a high priority on low operational costs associated with energy when looking for a property to rent or buy, and any discernable trends regarding this. No real estate agencies could say this was a high priority for consumers.

6. DISCUSSION

New housing stock is likely to remain for the next 50 years, thus it is important for designers and architects to strive to adopt PSD principles at the design stage. The results of this study supports Peterkin's position that PSD is currently not prevalent in Australia. This suggests missed energy saving opportunities, with such savings calculated to range from 10 to 28% can be realised with optimum orientation of new housing in Brisbane, with brick veneer homes having higher energy requirements than timber. This is important to note, given the popularity of brick veneer in new residential homes (e.g. master planned communities by volume builders). Based on Morrissey et. al. (2011) who concluded that the higher the energy rating, the smaller the effect orientation has on thermal performance, there is scope for more policy measures and education to take advantage of cost-effective energy savings opportunities via passive solar design.

Indeed, cost-effectiveness is key for promoting orientation and PSD to policy makers. According to Kruzner et. al. (2013), "if passive solar design was used to realize these reductions in just 10% of U.S. homes, projected energy and cost savings would be 531 trillion btu/year and 6 billion USD/year, respectively. The ENERGY STARs rebate program, by comparison, has saved an estimated 1.7 trillion btu/year, or approximately 150 million USD/year [based on U.S. Department of Energy 2011 statistics]"

In turn, this can contribute to the reduction of peak loads and defer network investments that are driving up energy prices. Indeed, fuel poverty is an emerging social problem for low-income households, and appropriate orientation is a PSD means to address both affordability of housing purchase (as orientation requires minimal or low design and construction cost) and affordability of housing operation (through reduced energy requirements).

Additionally, PSD through appropriate orientation can assist in achieving other cross-cutting policy objectives e.g. fuel poverty. Reducing energy demand will alleviate the pressures on a network currently at capacity, and defer network investment required otherwise to meet peak demand that is currently driving energy prices for end-consumers. Reducing energy demand will also reduce GHG emissions associated with fossil-fuel based energy sources. PSD is thus a means in some way to provide a clear policy link between climate change with sustainable residential development and social policy.

6.1 IMPLICATIONS FOR DECISION MAKERS

- There is a large scope for influencing the energy demands of new housing through stipulating PSD in the building code.
- The importance of demand-side measures cannot be neglected. The Federal Government’s proposed Mandatory Residential Disclosure to rectify the lack of information source of market failure is a step in the right direction in bringing more into focus energy consumption and climate change considerations. Currently operational costs considerations are far outweighed by other buyer considerations such as location, in the decision making process. This study helps to clarify that

orientation can play a key role in operational costs, and that this must be taken into consideration when implementing mandatory disclosure

- In a cost-driven building industry, PSD in part can address the split incentives/ broken agency dilemma in landlord-tenant arrangements.

6.2 FURTHER RESEARCH

This study can be expanded to investigate:

- Impact of climate change of two and multi-story residential buildings
- Other PSD parameters, in order for retrofit energy efficiency measures to be prioritised
- Thermal performance of housing on a development scale
- Ramifications of climate change on existing housing stock

7. CONCLUSION

This study set out to investigate if new developments have taken into account of passive solar design principles since energy efficiency regulations were introduced in 2003 in Australia. It is found that there is no evidence to suggest that orientation of housing or living areas within the house were a key consideration in the design and construction of new homes. The potential benefit of reduced energy requirements and subsequent greenhouse emissions (depending on fuel mix) may be in the order of 22 to 28%. Hence this study supports the conclusion that passive solar design can provide an important and low-cost step towards reducing environmental impacts as well as achieving other cross-cutting policy objectives, such as reducing fuel poverty.

The results of analysing material type and climate change scenario in this paper on heating and cooling energy requirements of houses constructed to current building energy efficiency regulations suggest that the housing sector requires effective policy measures and education to bring it in line with broader sustainable development and energy reduction goals.

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APPENDIX A

Spreadsheet record (excerpt)

					Orientation (Longitudinal Axis)	Orientation (Li
1	A001624588 - House in DCP (New House	118 CRESCENT RD HAMILTON QLD 4007	2004-01-07			
2	A001625108 - House in DCP (New House	14 AVEBURY ST WEST END QLD 4101	2004-01-09			
3	A001625650 - CP137 HOUSE IN DCP (NE	23 NEWMARKET ST HENDRA QLD 4011	2004-01-13			
4	A001625657 - House in DCP (New House	101 CHESTNUT ST WYNNUM QLD 4178	2004-01-15			
5	A001616354 - House in DCP (New House	156 KENT RD WOOLOOWIN QLD 4030	2004-01-21		E-W	S
6	A001616355 - House On Small Lot, Hous	154 KENT RD WOOLOOWIN QLD 4030	2004-01-23			
7	A001612754 - House in DCP (New House	23A ELAM ST WINDSOR QLD 4030	2004-01-30			
8	A001628400 - House in DCP (Demolition	62 LIVERPOOL RD CLAYFIELD QLD 4011	2004-01-30		E-W	N
9	A001628942 - House in DCP (New House	10 BERRINGAR ST WYNNUM QLD 4178	2004-02-02			
10	A001629479 - House in DCP (New House	39 CORUNNA ST ALBION QLD 4010	2004-02-03			
11	A001631403 - House On Small Lot, Hous	1649 SANDGATE RD VIRGINIA QLD 4014	2004-02-06			
12	A001631107 - House in DCP (New House	47 THIRD AVE SANDGATE QLD 4017	2004-02-11			
13	A001625141 - House in DCP (New House	91 GLOUCESTER ST SOUTH BRISBANE QLD 4101	2004-02-23			
14	A001611095 - House in DCP (New House	23 WAKEFIELD ST ALBION QLD 4010	2004-02-24			
15	A001625147 - House in DCP (New House	24 ATKINSON ST HAMILTON QLD 4007	2004-02-24		N-S	S
16	A001625684 - House in DCP (New House	45 PAROOBA AVE CAMP HILL QLD 4152	2004-02-25			
17	A001630144 - House in DCP (New House	229 WEBSTER RD STAFFORD QLD 4053	2004-02-26			
18	A001626251 - House in DCP (New House	34 DENNIS ST INDOOROOPILLY QLD 4068	2004-03-01		N-S	N
19	A001619573 - House in DCP (New House	100 BOYD RD NUNDAH QLD 4012	2004-03-05		E-W	W
20	A001627870 - CP137 HOUSE IN DCP (NE	27 LUDLOW ST HAMILTON QLD 4007	2004-03-05			
21	A001627889 - House in DCP (New House	39 HARDING ST HENDRA QLD 4011	2004-03-08			
22	A001630066 - House in DCP (New House	15 PANSY ST WYNNUM QLD 4178	2004-03-16			