Identifying Cost Savings through Building Redesign for Achieving Residential Building Energy Efficiency Standards

Final Report

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Prepared by: Sustainability House

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About Sustainability House

Sustainability House (incorporating House Energy Rating) is one of Australia's leading companies offering energy efficiency modelling, simulation and design advice for both residential and commercial buildings. The company has been operating in this market since 2000, and has developed significant industry experience and leadership to help build better buildings. For further information visit: www.sustainabilityhouse.com.au

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Abbreviations

ACT	Australian Capital Territory
BASIX	Building Sustainability Index
BCA	Building Code of Australia
CSOG	Concrete Slab on Ground
DCCEE	Department of Climate Change and Energy Efficiency
DTS	Deemed to satisfy
FCS	Fibre cement sheet
NatHERS	Nationwide House Energy Rating Scheme
NSW	New South Wales
NT	Northern Territory
RIS	Regulation Impact Statement
SA	South Australia
TAS	Tasmania
VIC	Victoria
QLD	Queensland
WA	Western Australia

Executive Summary

Key Findings

- Current popular designs as constructed by Australia's largest volume builders can meet the 6 star energy efficiency standard with reduced construction cost if the design is modified to best suit the climate and orientation rather than increasing the building specifications, eg. insulation levels.
- Results of this study show an average increase in energy efficiency of 1 star, and an average decrease in total construction cost of nearly 2%, compared to the original design.
- Buildings which are designed for climate and orientation, particularly the location of living areas and the placement and size of glazing show cost effective increased energy efficiency and occupant comfort.
- Buildings can achieve the 6 star minimum requirement without substantial loss of glazing area.
- There are a range of climate dependent no-net cost changes which can improve thermal performance including optimisation of roof colour, moving glazing from east/west to north/south orientation, mirroring of building design and polystyrene core floor slabs.

Context

The traditional approach to estimating the cost impact of increases in residential building energy efficiency standards has been to increase the specification of a design until the required energy efficiency benchmark is reached. There are concerns that this method overestimates the impact on the cost of the building.

The intention in this report is to use understanding of climate and thermal design principles to make relatively simple changes to the design of the building, then using an automated tool, identify building specifications that achieve the least cost energy efficiency improvements.

Methodology

Twenty designs were assessed using builder supplied specifications in all eight capital cities and four orientations. Designs were sourced for a range of dwelling types (single and double storey detached, semi-detached and apartments) from twelve of the largest residential construction companies across Australia. Builders' specifications were adjusted for each design to meet 6 stars in Adelaide and Canberra and 5 stars in all other cities.

Each building was redesigned in a selected orientation. Orientations were selected to provide a sample of best, worst and intermediate orientations. The buildings in the selected orientation were redesigned to meet 6 stars in all capital cities.

The redesign process involved the manual application of thermal design principles and an automated comparison of possible specification options using Roborater. Developed by Sustainability House, Roborater allows the rapid simulation across a wide range of variables including insulation, orientation, windows, shading and cladding colours. Roborater improved the scope of the study by making it possible to identify the most cost effective design combinations.

Cost estimates for the initial and redesigned building were supplied by an independent quantity surveyor, Davis Langdon.

Results

On average, all buildings in all climates were able to meet the 6 star energy efficiency requirement with a decrease in construction cost. The average increase in star rating was one star. The average decrease in cost was 1.6% of the total construction cost.

Original Designs

The original designs used a range of specifications to meet the starting energy efficiency requirement. Some buildings required costly specifications such as double glazing while others achieved over 6 stars with reduced specification.

- Double storey designs achieved the lowest average star rating
- Apartments positioned on the corner of the building rated highest
- Brisbane achieved the lowest average star rating
- Hobart achieved the highest average star rating

The average star rating varied with orientation by 0.5 stars for detached dwellings and 0.8 stars for semi-detached dwellings.

Redesigned Dwellings

The redesign of dwellings resulted in an energy efficiency improvement of one star which was also associated with a cost reduction of nearly 2%. Redesigned dwellings achieve an average star rating of 6.3.

High Volume Residential Builder Survey

A survey of the participating builders was conducted as part of the study. Survey results identified conflicting priorities in meeting increasing energy efficiency regulations. In summary, survey respondents:

- estimated average construction cost increases of approximately $3500 for moving from 5 to 6 stars;
- identified block layout in developments as a barrier to improving energy efficiency;
- suggested increased education of home buyers and sales staff would be beneficial to the general acceptance of higher requirements for energy efficiency.

Conclusions and Recommendations

Current volume building designs have the potential to be energy efficient at a lower cost than currently incurred by builders. However current designs are intended to be constructed in all orientations and are designed with windows distributed evenly around the building leading to average performance in all orientations.

The study found that the star rating could be improved significantly and cost effectively by:

- Tailoring designs to different orientations and climate types
- Selecting the best orientation for a given dwelling
- Changing building specification based on climate.

There may be barriers to making these changes including: subdivision layout, lack of home buyer understanding and increased costs associated with optimising designs at the design stage.

A number of areas were highlighted by the study for future research, including the effect of sub-division block layout on the energy efficiency of dwellings.

Introduction

Background

Building regulation for energy efficiency was introduced into the Building Code of Australia in 2003. The energy efficiency of residential buildings can be measured by the use of accredited simulation software known as Nationwide House Energy Rating Scheme (NatHERS) software.

The software estimates the internal temperature in each room of a dwelling for each hour of the year based on assumptions about occupant behaviour, information about the structure and specification of the dwelling and standard weather data for the dwelling's location.

The internal temperature is compared against a comfortable temperature range and occupancy pattern to estimate the annual heating and cooling loads per square metre of floor area to keep the temperature within the comfort range. The loads are adjusted and converted into a star rating between 0 and 10. A 10 star home is unlikely to need any artificial cooling or heating to maintain comfortable internal conditions, whereas a 0 star home would offer virtually no protection from the external temperature.

The BCA sets a minimum acceptable thermal performance rating by specifying a minimum star rating.

Increased Stringency to Energy Efficiency Regulation

The 2009 COAG National Partnership Agreement on Energy Efficiency effectively increased the minimum acceptable standard for residential buildings from 5 to 6 stars using NatHERS approved software. The change was introduced to the BCA in May 2010, along with minimum performance standards for lighting, hot water generation and other measures. The ACT was the only jurisdiction to implement the change immediately. All other jurisdictions delayed the introduction for various periods. At the time of writing, all states except NSW, NT and TAS have introduced the 6 star requirement.

BASIX

Besides NSW, all states regulate residential building energy efficiency using the BCA. NSW uses a web based tool called the Building Sustainability Index (BASIX). Water and energy usage for appliances and hot water generation are assessed in addition to thermal performance. Thermal performance can be assessed with either prescriptive DTS like 'Rapid' and 'DIY' checklists or through the use of NatHERS software. Instead of the star rating system BASIX places maximum allowable caps on the heating and cooling loads. To keep the study methodology consistent across Australia, this study does not take into account the use of BASIX in NSW.

Drivers for this Research

Since the first energy efficiency regulations were introduced in 2003, there have been some concerns expressed by some parts of the building industry in relation to meeting the minimum energy efficiency requirements. Over the last decade regulation of building construction has continued to increase in stringency and complexity which has resulted in cost increases to the industry in several ways. Additional costs are also borne by the industry in interpreting and adapting to regulation changes in terms of business practices and housing design.

One of the main areas of concern raised in some sections of the building industry has been in the perception of the increase to construction costs when meeting more stringent energy efficiency standards. These perceived extra costs are typically passed on to the home owner causing housing affordability concerns. However, in general the increased costs have been estimated by taking a typical home as currently built and adding to the specification to meet the new standard, rather than looking at modifying the design as the primary means of achieving the standard and adjusting the specifications to suit the modified design.

For example the Regulation Impact Statement (RIS) for the 2010 Building Code of Australia (BCA) changes estimated the cost of “adding on” higher performing building elements and materials to existing house designs and compared these costs to the estimated long term energy savings from having a more efficient building.

This approach does not consider how costs can be minimised by redesigning the building to integrate energy efficiency features and by tailoring standard house designs to different block orientations and climate zones. Concerns have been raised that this traditional approach is over-estimating the incremental construction costs of achieving higher star rated houses and may be misrepresenting the economic impacts of improved building standards.

Aim

Sustainability House was contracted by the DCCEE to determine the extent to which the cost of achieving the 6 star BCA performance standards in typical new residential buildings can be reduced through changing the design of the building, while still maintaining building features, functionality and size, before upgrading the specification.

To achieve this aim Sustainability House sourced current popular plans and specifications from a number of builders across Australia. The plans were assessed using NatHERS software and the specifications adjusted to achieve 5 stars in all capital cities except Adelaide and Canberra where they were required to meet 6 stars. This difference was included because Adelaide and Canberra have had the 6 star requirement in place for the longest period. In the other cities the transition to 6 stars is still occurring or has not yet started.

The plans were then redesigned using a combination of a manual and an automated process to achieve 6 stars. In the case of Adelaide and Canberra the redesign was to determine a more cost-effective means of achieving the existing 6 stars. Costs for changes needed to get buildings to the 6 star standard were estimated by an independent quantity surveyor, Davis Langdon.

An additional aim of Sustainability House is to provide results that can broadly guide energy efficiency assessors in design strategies to cost-effectively meet energy efficiency regulations for different dwellings types and capital cities.

It should be noted that the emphasis of the study was to find the least cost path to improve the building. In some instances this went against industry norms and standard customer expectations, which suggests that these norms and expectations have arisen without consideration of the impacts on the home’s energy efficiency.

Methodology

House Design Selection

To provide an extensive appraisal of the housing industry, a range of the most common dwelling types were assessed. In total 20 unique designs were included in this study which comprised the following dwelling types:

- 6 x Single storey detached;
- 6 x Double storey detached;
- 2 x Semi-detached houses with one shared wall;
- 2 x Semi-detached houses with two shared walls;
- 2 x Apartments located on the corner of an apartment block;
- 2 x Apartments located in the middle of an apartment block.

The study used a larger sample size for detached houses than other dwelling types for two main reasons. Firstly, statistics confirm that in Australia detached houses are more frequently constructed than semi-detached houses or apartments, so the number of dwelling types included in this study reflects this trend. Secondly, semi-detached houses and apartments tend to be less responsive to a range of design changes in NatHERS software than detached houses. Due to the effect of shared walls, floors or ceilings and limitations to the number of exposed facades, these dwelling types tend to be strongly influenced by changes to orientation and glazing and less so by other factors. Consequently more insights into cost effective redesign options could be provided by using a larger number of detached houses than other dwelling types.

Market research was initially used to identify standard house designs in each capital city using HIA data, web research and direct contact with many of the top 100 house builders in Australia. This research confirmed that high volume residential builders commonly construct the same designs across much of Australia, with minor changes to building specifications to meet thermal performance requirements in different climate zones. WA was an exception to this trend where it was found that residential construction is dominated by a few companies that only build in this state, and consequently these designs aren't built across multiple jurisdictions.

The fact that residential construction companies build the same or similar designs across multiple states and territories formed the basis for the study design. Based on this finding we decided to assess the same 20 dwellings in every capital city in Australia. This decision was also influenced by the fact that the study had access to semi-automated software which could easily assess any modelled dwelling across multiple locations (as detailed below in *Automated Assessment* methods).

A benefit of this study design was that it allowed the opportunity to compare the effectiveness of designs and construction methods across multiple climate zones. It also allowed assessment of a far greater number of dwellings in each capital city than would have otherwise been possible.

The dwelling designs in the sample are not all marketed in every state and territory, but were selected to ensure that for each state and territory there is at least one of the single storey and one of the double storey house designs that is marketed there. Due to the smaller sample size of semi-detached houses and apartments it was not possible to include a representative example of these dwelling types for every state and territory, however every effort was made to ensure that those that were selected provided the maximum coverage in this respect.

The house designs were selected to provide a representative sample of commonly used designs in the market, as identified through market research. They do not however provide a statistical sample of designs in the residential housing market and to some extent the study relied on residential builders to provide “common” designs.

Plans and specifications of all original and redesigned dwellings are provided in Appendix 3: Dwelling Reports, which is in a separate document.

Dwelling Designs

Single storey dwellings encompassed a range of sizes from 125 to 303m² (inclusive of garage and covered outdoor areas), with either 3 or 4 bedrooms. In terms of overall design shape, dwellings were selected to encompass a range of typical layouts, including compact squarish designs to long, elongated designs.

The double storey dwellings ranged in size from 142 to 460m², and varied in the number of bedrooms from three to five, although the most common number of bedrooms was four. As with the single storey designs, a range of design shapes typical of project homes were included in the study, but which would also respond differently to assessment of energy efficiency.

The four semi-detached designs included two single and two double storey designs, one each for the one- and two shared wall designs. Typical of this dwelling type the designs were all quite compact with a total area ranging from 123 to 169m². Most semi-detached designs included three bedrooms, although a two bedroom design was also assessed.

In terms of the apartment designs, a middle and corner apartment design was selected from two different apartments. One of the apartments was a conventional apartment design where the middle and corner apartment had one or two exposed façades respectively. These apartments were also quite small, with total floor areas of 87 and 100m², and either one or two bedrooms. The other apartment was a flow through design, where the middle and corner apartments had two and three exposed facades respectively. These apartment designs were also around twice the size of the other apartments, both with 3 bedrooms.

Dwelling Construction Types

A range of typical construction types was included in the study for single and double storey designs. In terms of floor construction all but one design consisted of a concrete slab on ground, which is most typical of the market. The other floor type included in the study was a raised timber floor, which is a less common standard construction for project homes. Generally for two storey designs the upper floor was a timber construction, however a suspended concrete floor was also included in this study as this was more representative of WA designs.

For single and double storey designs external wall construction was most commonly brick veneer, although lightweight cladding was included for one single storey design and the second level of some double storey designs. Also included in the study were a single and double storey design constructed from double brick, with single brick internal walls. This construction type is most typical of that used in WA. For these dwelling types roof constructions were typically metal deck, but a number of dwellings had concrete tiles.

Construction types were the same between all semi-detached dwellings, comprising of a concrete slab on ground floor, brick veneer external walls and metal roof. As with the semi-detached dwellings, the construction materials were also standard across all apartments. External walls were concrete with suspended concrete floor and roof.

Modelling Techniques and Assumptions

The 20 dwellings chosen for this study were rated in accordance with the Protocol for House Energy Rating Software Version 2006.1, Protocol for House Energy Rating Software for Residential Buildings Version 2006.1 and the AccuRate Help File. AccuRate Version 1.1.4.1 was used for all thermal simulation.

Various assumptions where made whilst modelling the dwellings, based on the AccuRate Help File and technical experience of Sustainability House assessors:

- Detached shading structures (fences, neighbouring buildings, trees, etc.) have not been assessed, with the exception of Dwelling 16 which has a detached garage;
- All shading schemes (balcony, outdoor living area, etc.) have a 100% blocking factor;
- All wet areas without windows are zoned as conditioned space with a sealed exhaust fan;
- All wet areas with windows are zoned as non-conditioned space, and where applicable these areas are zoned together;
- Ensuites and walk-in-robes are assessed as part of the bedroom, with the exception of ensuites accessed by two doors;
- Where possible, access ways (hallways, etc.) are zoned separately from the living and kitchen areas.

Specification assumptions that are consistent for modelling of all original dwellings are detailed below:

- The external colour of the roof and walls has been set to the default of medium, with a solar absorptance of 50%;
- Floor coverings are assumed absent in the garage, tiles for wet areas and kitchen, and carpet elsewhere.

Specification assumptions that are consistent for modellings of all original and redesigned dwellings are detailed below:

- As a requirement of the BCA 2011 steel framed buildings are required to have a thermal break (minimum R0.2) installed between the external cladding and the metal frame. We have assumed foam strips for all steel frame buildings with light weight cladding;
- All windows and external doors have weather-stripping;
- Insect screens to openable windows only;

- Internal walls 10mm plasterboard on studs, unless otherwise specified.

There are also a number of inherent assumptions within the NatHERS benchmark software AccuRate Version 1.1.4.1. For more detailed information please refer to the NatHERS website.

The dwellings were initially modelled in one climate zone and four orientations. The direction of the front door is used to describe the orientation of all dwellings, except for the apartments in which the main glazing determines the orientation. AccuRate scratch files were then generated for all designs and used to automatically run the simulation model across the eight climate zones and four orientations. Standard construction specifications and improvements paths were used to achieve the star rating requirements for each location (refer to *Methods: Automated Assessment* for further information about this approach).

Climate Zones and Climate Types

In each capital city the dwellings were assessed in one climate zone, however within some of the capital cities there were several possible climate zones. To select climate zones in these instances, HIA data was used to identify the climate zones with the highest number of residential buildings being constructed, or where there is likely to be the most construction in the near future.

The three climate types (hot, temperate and cold) were assigned based on initial results of dwelling performance across different climates and were used to group dwellings for the redesign process only. As a sub-tropical climate Brisbane could have been grouped as hot or temperate as it responds well to redesign for both climate types, but was assigned to the temperate category for the purpose of this study.

A summary of the climate zone and climate type selected for each capital city in this study is provided in Table 1 below.

Table 1: Climate zones and postcode used in AccuRate to assess dwellings in each capital city in Australia together with climate type category assumptions.

Capital City	Climate Type	Climate Zone	Postcode
Darwin	Hot	1	0800
Brisbane	Temperate	10	4000
Perth	Temperate	13	6065
Sydney	Temperate	28	2753
Adelaide	Temperate	16	5000
Canberra	Cold	24	2600
Melbourne	Cold	60	3024
Hobart	Cold	26	7018

Original Dwelling Specifications

As each dwelling was assessed in every capital city, standard specification changes were necessary for the original dwellings to meet the minimum energy efficiency rating in each location. Although many of the sourced plans were built in the majority of capital cities in Australia, none of the plans were built in every capital city. In addition, many of the 'off-the-plan' specifications did not meet the minimum star rating target of 5 or 6 stars (dependent on location). Consequently it was necessary to complete this process for all of the original dwellings and fill-in missing specifications.

To facilitate this process the specifications for the original designs were primarily sourced from the construction companies that provided plans for the study for as many capital cities as possible. For those locations where specifications and standard upgrade pathways to meet energy efficiency requirements were not available, missing data was extrapolated based on typical specifications provided by other companies for the capital cities. Where specification upgrades for the original dwellings were necessary professional consultancy experience was applied to minimise design costs for the original dwellings where specification upgrades were required.

Where specification upgrades/ changes were necessary to meet the minimum 5 or 6 stars, improvements included:

- Insulation variations to the external walls, internal walls, floor and/or ceiling;
- Addition of reflective foils to the roof;
- Improved glazing systems;
- Adjustable shading devices to all windows.

These methods ensured that the original dwelling designs met star rating requirements in all capital cities using specifications typically used by project home builders.

Dwelling Redesign

For each capital city the 20 dwellings were redesigned in a single orientation which was selected based on: a) professional design judgement, where some orientations were deemed more conducive for redesign, and/or; b) star rating results of the four cardinal orientations for the original design. In many instances if the original design rated highly (i.e. around 6 stars) then a poor performing orientation was selected for redesign, whereas an intermediate or higher performing orientation may have been selected for redesign if the original design performed poorly. This method for selecting orientation for redesign meant that a range of best, worst and intermediate performing orientations were included in the redesign process.

As a general rule dwellings were redesigned by climate type rather than climate zone. For the purpose of the study we grouped capital cities into one of three climate types: hot, temperate and cold (refer to Table 1 for details). Justification of this approach is based on our experience that we have found climate types respond similarly to design changes. This method also significantly reduced the number of manual redesign changes to a more manageable size for the manual redesign stage of 60 or so (3 climates x 20 dwellings) rather than 160 dwellings (8 capital cities x 20 dwellings).

The first stage of the redesign process for each dwelling involved a series of manual changes in AccuRate, which was followed by automated redesign changes to find the most cost-effective specifications. Manual design changes included but were not limited to the following changes:

- Internal room layout/ zoning;
- Glazing relocation and size reductions;
- Ventilation;
- Orientation;
- Shading;
- External wall construction.

Following manual remodelling of dwellings, scratch files were generated to use for the automated redesign process. The automated redesign process included the same specification changes such as insulation levels and glazing types, as for the original dwellings, as well as the following additional variations:

- Window width reduction to all windows (in addition to any manual window reductions);
- Eave width (all orientations);
- External cladding colours (generally only roof colour);
- Adjustable shading devices to specific windows;
- Floor coverings to living areas in hot and temperate climates only;
- Polystyrene core to concrete slab in cold climates only.

Redesigned specification results are presented in tables in Appendix 3 that incorporate all capital cities for each dwelling. Tables are colour-coded using three colours to compare with original specification for a given location: red (■) indicates a specification cost increase to the original specification, green (■) indicates a specification cost decrease to the original specification, and blue (■) indicates a no-net cost specification change.

Other redesign changes are presented as redesigned plans by climate type and/ or capital city. Redesign changes that are only presented on the plans include:

- Room layout and zoning changes (e.g. room layout changes such as plan mirroring or the addition of internal doors to change zoning from conditioned to unconditioned);
- Glazing relocation and specific size reductions;
- Floor coverings;
- Whirlybirds;
- Ceiling fans.

All of the redesign changes detailed above are shown on the floor plans in red with a blue number immediately adjacent to the change. Each number corresponds to a brief description of the redesigned change in a legend below each redesigned plan.

Star rating results for redesigned dwellings are presented in a table that includes all capital cities, together with total redesigned cost and cost saving compared to the original dwelling.

The table also includes star rating change, which is a comparison with the original star rating in the *same* orientation, not the star rating for the worst orientation.

Star Rating Performance Requirements for Original and Redesigned Dwellings

At the time of this study, 6 star requirements had not yet been adopted in NSW, NT and TAS. In addition 6 stars had only been recently adopted in VIC and WA, providing little time for project home builders to redesign their range of homes to 6 star. Whilst QLD adopted 6 star requirements in 2010, they have one star credits for outdoor living areas and photovoltaic cells, so it is more likely that the standard designs in QLD achieve closer to 5 stars. ACT and SA were considered to be the only jurisdictions to have fully implemented 6 stars in 2010.

For all of the reasons outlined above, the original dwellings were only required to achieve 6 stars in ACT and SA for the purpose of this study and in all other locations 5 star minimum performance requirements applied (Table 2). Consequently the study assessed the incremental cost increase of moving from 5 to 6 stars in all capital cities except for ACT and SA where the study aimed to identify ways to achieve 6 stars more cost-effectively. Redesigned dwellings in all capital cities were required to meet a minimum of 6 stars.

Table 2: Star rating requirement for the original and redesigned dwellings by capital city.

Capital City	Initial required star rating	Required star rating after redesign
Darwin Brisbane Perth Sydney Melbourne Hobart	5	6
Adelaide Canberra	6	6

Automated Assessment

This study employed automated simulation software, independently developed by Sustainability House, to rapidly and cost-effectively assess a large number of specification combinations for the original and redesigned dwellings. This software tool, which is aptly named Roborater, facilitates mass simulation of multiple design iterations of buildings modelled in NatHERS software. Whilst a human operator could assess a maximum of two building designs per minute, Roborater can automatically assess more than 2000 designs per minute. The following hypothetical example in Table 3 provides an indication of the capabilities of Roborater.

Table 3: Example of variables assessed by Roborater and the total number of possible design combinations with these variables.

Design Variation	Number of Variations	Total Number of Design Combinations
Dwelling	20	20
Climate zones (cities)	8	20 x 8 = 160
Orientations	4	160 x 4 = 640
External wall insulation	3	640 x 3 = 1,920
Internal wall insulation (house)	3	1,920 x 3 = 5,760
Internal wall insulation (garage)	3	5,760 x 3 = 17,280
Ceiling insulation	3	17,280 x 3 = 51,840
Roof insulation	3	51,840 x 3 = 155,520
Glazing/frame system	8	155,520 x 8 = 1,244,160
Awnings	2	1,244,160 x 2 = 2,488,320
Eave width	3	2,488,320 x 3 = 7,464,960

Roborater was originally developed as a research tool for looking at permutations of design and construction materials against thermal performance in multiple climate zones and orientations, so this project provides the perfect application of this software. However this software has also proven highly suited to the assessment of individual dwellings to quickly and cheaply identify the most affordable and/or energy efficient design combinations.

Both original and redesigned dwellings were run through Roborater. For the original designs, Roborater allowed the rapid assessment of dwellings in all capital cities and four orientations. Due to timeframe limitations of this study, original designs were only required to achieve within 0.2 stars of the minimum star rating of 5 or 6 stars in each capital city. Upgrade pathways as specified by project home builders were applied to find the base specifications, which typically encompassed the most cost effective specification combinations to achieve the star rating. However base specifications as provided by project home builders also achieved higher than the minimum star rating requirements for some dwelling designs.

Following manual redesign changes of dwellings in one orientation, the redesigned dwellings were run through Roborater to find the most cost effective specification to meet 6 stars. In a small amount of cases where optimal results were not achieved in the initial redesign process, a second redesign process was undertaken and a subsequent Roborater run to optimise designs. The limited duration of the contract did not allow for further consideration of optimal redesign changes beyond this extent.

Cost Estimates

Dwelling cost estimates were completed by Davis Langdon (Adelaide); a national quantity surveying firm with offices in all capital cities in Australia.

Cost estimates were initially prepared for Adelaide using rates benchmarked from cost data derived from similar projects. The data is regularly reviewed and revised to reflect the current market conditions. Estimates for other capital cities applied a respective locality adjustment factor which was sourced from Rawlinsons Construction Cost Guide 2011.

Costs estimates are provided as total construction costs to home owners. A schedule of rates for each redesigned building element is provided in Table 4.

Feedback from project builders indicated that the cost estimates prepared by Davis Langdon were generally higher than real world prices of project home builders. Variations may be due to such factors as site preparation costs, internal fit-out specifications and bulk discounts obtained from suppliers. Due to this variation costs are also presented as percentages (e.g. percentage cost saving).

Table 4: Schedule of residential construction rates by state.

Location Factor			**1.18**	**1.30**	**1.23**	**1.07**	**1.00**	**0.98**	**0.95**	**0.98**
Item	**Specification**	**Rate Basis**	**NT**	**QLD**	**WA**	**NSW**	**SA**	**ACT**	**VIC**	**TAS**
Timber floor insulation	R1.5	per m²	$12	$13	$12	$11	$10	$10	$10	$10
Timber floor insulation	R2.0	per m²	$14	$16	$15	$13	$12	$12	$11	$12
Between floor insulation	R1.5	per m²	$12	$13	$12	$11	$10	$10	$10	$10
Between floor insulation	R2.0	per m²	$14	$16	$15	$13	$12	$12	$11	$12
Wall insulation	Single sided foil	per m²	$8	$9	$9	$7	$7	$7	$7	$7
Wall insulation	Double sided foil	per m²	$17	$18	$17	$15	$14	$14	$13	$14
Wall insulation	R1.5	per m²	$12	$13	$12	$11	$10	$10	$10	$10
Wall insulation	R2.0	per m²	$14	$16	$15	$13	$12	$12	$11	$12
Wall insulation	R2.5	per m²	$17	$18	$17	$15	$14	$14	$13	$14
Ceiling insulation	R2.0	per m²	$14	$16	$15	$13	$12	$12	$11	$12
Ceiling insulation	R3.5	per m²	$19	$21	$20	$17	$16	$16	$15	$16

Ceiling insulation	R4.0	per m²	$21	$23	$22	$19	$18	$18	$17	$18
Roof insulation	Reflective foil	per m²	$6	$7	$6	$5	$5	$5	$5	$5
Concrete floor	Slab on ground	per m²	$124	$137	$129	$112	$105	$103	$100	$103
Concrete floor	Polystyrene core	per m²	$124	$137	$129	$112	$105	$103	$100	$103
Floor covering	Carpet	per m²	$47	$52	$49	$43	$40	$39	$38	$39
Floor covering	Vinyl	per m²	$77	$85	$80	$70	$65	$64	$62	$64
Ceiling fan	1200mm	each	$295	$325	$308	$268	$250	$245	$238	$245
Whirlybirds	(allowance)	each	$2,950	$3,250	$3,075	$2,675	$2,500	$2,450	$2,375	$2,450
Window system	Alum frame, 3mm clear	per m²	$413	$455	$431	$375	$350	$343	$333	$343
Window system	Alum frame, 5mm single Evergreen	per m²	$590	$650	$615	$535	$500	$490	$475	$490
Window system	Alum frame, 6.38 CP neutral	per m²	$590	$650	$615	$535	$500	$490	$475	$490
Window system	Alum frame double 4mm clr/8mm air/ 4mm Energy Advantage Low E	per m²	$826	$910	$861	$749	$700	$686	$665	$686
Window system	Cedar frame, 3mm single clear	per m²	$413	$455	$431	$375	$350	$343	$333	$343
Window system	Cedar frame, 6.38 CP neutral	per m²	$590	$650	$615	$535	$500	$490	$475	$490
Window system	Cedar frame, double 3mm clear/ 6mm air/ 3mm clear	per m²	$767	$845	$800	$696	$650	$637	$618	$637
Window system	Cedar frame, double 4mm clr/8mm air/ 4mm Energy Advantage Low E	per m²	$826	$910	$861	$749	$700	$686	$665	$686
Awnings	Roller shutter	per m²	$295	$325	$308	$268	$250	$245	$238	$245
Roof system	Metal deck on frame	per m²	$171	$189	$178	$155	$145	$142	$138	$142
Eaves	4.5mm F/C	per m²	$83	$91	$86	$75	$70	$69	$67	$69
Wall type	Cavity brick	per m²	$283	$312	$295	$257	$240	$235	$228	$235
Wall type	Brick veneer	per m²	$195	$215	$203	$177	$165	$162	$157	$162
Wall type	Reverse brick veneer	per m²	$260	$286	$271	$235	$220	$216	$209	$216
Wall type	Lightweight (FCS)	per m²	$195	$215	$203	$177	$165	$162	$157	$162
Internal door	Single leaf, timber	each	$413	$455	$431	$375	$350	$343	$333	$343
Internal door	Double leaf, timber	each	$1,298	$1,430	$1,353	$1,177	$1,100	$1,078	$1,045	$1,078
Internal door	3.2m x 2.1m stacker	each	$3,540	$3,900	$3,690	$3,210	$3,000	$2,940	$2,850	$2,940

Building Plans

All original building plans were redrawn in order to remove company branding, scales and create consistency in styles between plans, however redrawn plans are not to scale. Despite the removal of company branding, copyright laws still apply and plans remain the property of the respective residential construction companies.

Case Studies

A number of case studies were prepared to provide overviews and insights into the effect of selected key variables considered in this study. Case study topics include:

- Glazing area and orientation;
- The effect of internal room layout and zoning;
- Roof colour;
- The effect of insulating concrete slab on ground and variable floor coverings;
- Shading;
- Ventilation;
- External wall construction and variable insulation levels for detached houses.

Case studies provided the opportunity to highlight how the above variables influenced the star ratings for the redesigned dwellings. A consequence of applying Roborater was the generation of surplus data not utilised in the building redesign and the case studies also provided an opportunity to present and interpret some of this additional valuable data.

Some case studies include data from the report and in these cases dwelling specifications are the same as the initial or redesigned dwelling in the report. For examples that were prepared specifically as case studies, specifications have been standardised across all capital cities.

High Volume Residential Builder Survey

All residential construction companies that provided plans for this study were invited to participate in a survey aimed at obtaining feedback from builders about their experiences of energy efficiency regulations and construction costs. In consultation with DCCEE, a series of 15 survey questions was developed and made available for construction company representatives to fill out via an online Google survey. A complete list of survey questions is provided in Appendix 2.

Although the survey does not provide a statistically valid sample of residential builders, responses were obtained from some of the largest residential construction companies in Australia. These companies represent a significant proportion of residential construction, so we believe that they do provide valid insights into experiences and concerns of residential builders in Australia.

Results

Performance of Original Dwellings

The 20 original designs were assessed in all eight capital cities and four cardinal orientations with standard specifications as supplied by residential builders, giving a total of 640 unique building combinations. While the specifications varied for different capital cities, they remained the same across the four cardinal orientations in each capital city.

For the majority of the original designs, the average star rating achieved across all orientations and capital cities was between 5 and 6 stars. The average star rating (across all orientations) for original designs in 5 star jurisdictions was 5.4 stars and the average was 6 stars in Adelaide and Canberra. Analysis of average star rating of the original designs by dwelling revealed that five of the 20 designs achieved an average star rating above 6 stars, while two designs averaged less than 5 stars across all capital cities and orientations (refer to Figure 1).

The highest performing design was a double storey semi-detached house with two shared walls (Dwelling 16), which achieved an average star rating of 6.6 stars, followed closely by a small middle apartment (Dwelling 18) at 6.4 stars. The other designs which achieved an average star rating above 6 stars were another semi-detached house (Dwelling 14), another apartment (Dwelling 20), and Dwelling 2, which was, on average, the most energy efficient detached house design. These designs provide good examples of where residential dwellings can actually exceed 6 star energy efficiency standards with standard 5 star specifications.

In contrast the poorest performing designs were a double storey detached house (Dwelling 7) and a single storey semi-detached house with two shared walls (Dwelling 15), which both averaged 4.9 stars. These dwellings had difficulty achieving the minimum star rating requirement and required high levels of insulation, high performance glazing and/or awnings to achieve 6 stars.

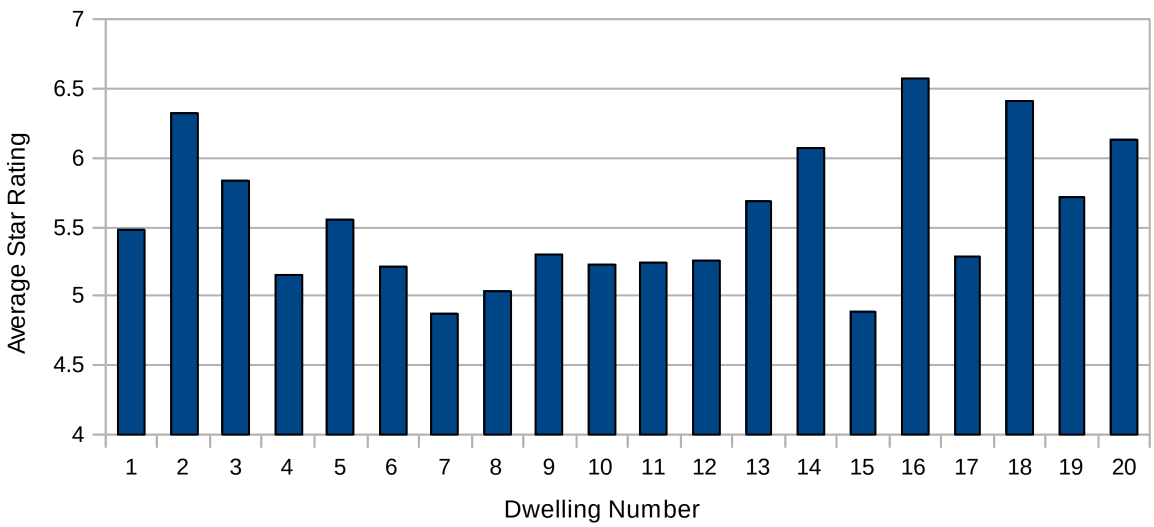

Figure 1: Average star rating for the original designs by dwelling number.

The original dwelling designs which achieved high star ratings across all assessed orientations with standard specifications provided limited scope for redesign. Consequently dwellings were not redesigned in 21 of the 160 building combinations, representing 13% of overall cases. Dwelling types that were not redesigned included a single storey detached house (Dwelling 3) at three different locations, and two semi-detached houses (Dwellings 14 & 16) and two apartments (Dwellings 17 & 20) in nine locations per dwelling type. Table 4 provides a summary of dwellings not redesigned in this study.

Table 5: Cases where dwellings were not redesigned listed by capital city.

	Dwelling number				
Capital City	**3**	**14**	**16**	**17**	**20**
Darwin	X	X			X
Brisbane	X				
Perth		X		X	X
Sydney		X	X	X	X
Adelaide	X	X	X	X	
Canberra			X	X	
Melbourne			X	X	
Hobart			X	X	

Note: “X” indicates locations in which dwellings were not redesigned.

For these five designs which were partially excluded from the redesign process, the original design averaged above 6 stars across the four cardinal orientations in all capital cities, with the exception of Dwelling 3 which averaged 5.8 stars (refer to Figure 1for average star ratings for Dwellings 1-20). While Dwelling 2 also averaged above 6 stars this dwelling was redesigned in all locations to reduce construction costs.

Performance of Original Dwellings by Dwelling Type

Analysis of the average star rating for the original designs by dwelling type (Figure 2) revealed that the double storey designs were the most inefficient dwelling type, achieving an average rating of 5.2 stars. This could be attributed to two main factors. The first is that double storey houses tend to have a higher wall area to floor area ratio. The other contributing factor is that double storey houses have a raised first floor which is not subject to passive thermal benefits of a concrete slab on ground floor. For thermal modelling purposes raised apartments are not subject to this effect because the same occupancy schedule is assumed to the adjoining floors, which essentially provides an insulating effect.

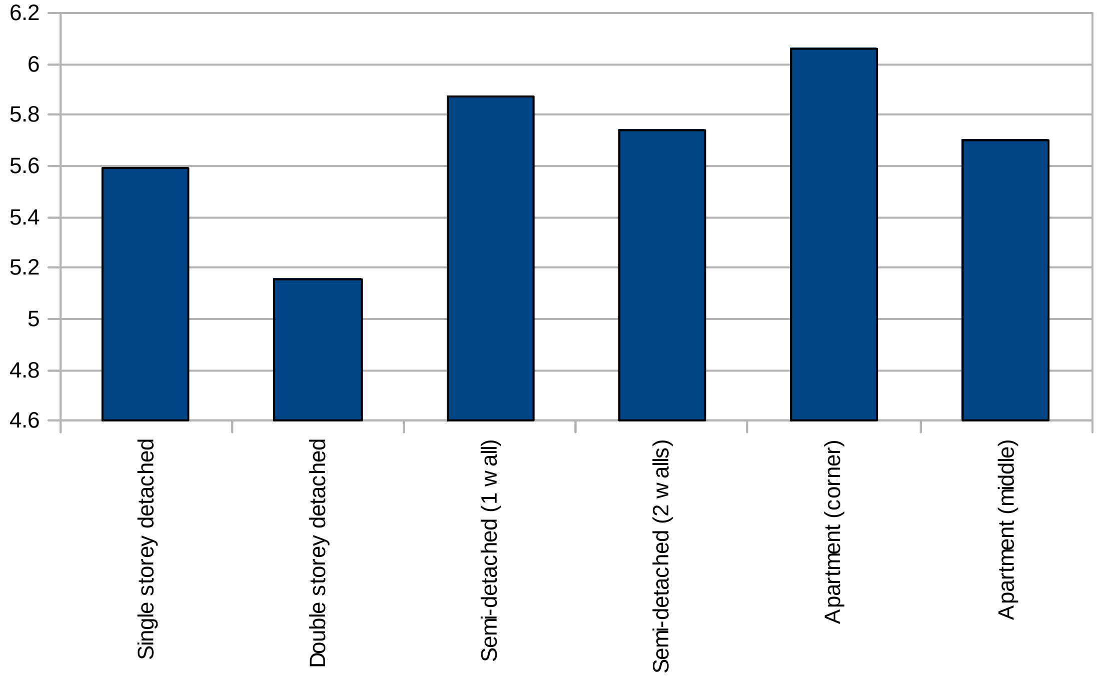

Figure 2: Average star rating for the original designs by dwelling type.

As the original designs were assessed in four orientations, rather than just one orientation, the dwelling redesign exercise provided an opportunity to look at the effect of orientation. The average variation between minimum and maximum star rating of the four cardinal orientations was calculated by dwelling type (Figure 3). This revealed a strong trend between dwelling type and orientation where the number of shared walls influenced the degree to which star rating varied between orientations.

In accordance with this trend, detached houses, with no shared walls, were moderately influenced by orientation and displayed about a 0.5 star variation between the minimum and maximum star rating across the four orientations. At the other end of the scale the energy efficiency of middle apartments, with three shared walls, was heavily influenced by orientation with an average variation of 1.5 stars. The reduced influence of orientation on detached dwellings can also be attributed to the fact that most of these dwellings had been designed with fairly even amounts of glazing to all facades which would reduce the effect of orientation.

These study findings suggest that detached dwellings may have their performance improved by an average of 0.5 stars by simply building in the optimal orientation. Similarly the star rating for semi-detached houses included in this study could be improved by an average of 0.8 stars if built in the best orientation.

This finding does not assume that builders are simply able to reorientate a dwelling on a particular block to achieve a higher rating as this is obviously restricted by block size and subdivision layout. The point is to illustrate that the dwelling orientation can have a significant impact on its energy rating and that efficiencies can be gained by choosing a house design that best matches the orientation of the block where it is to be built.

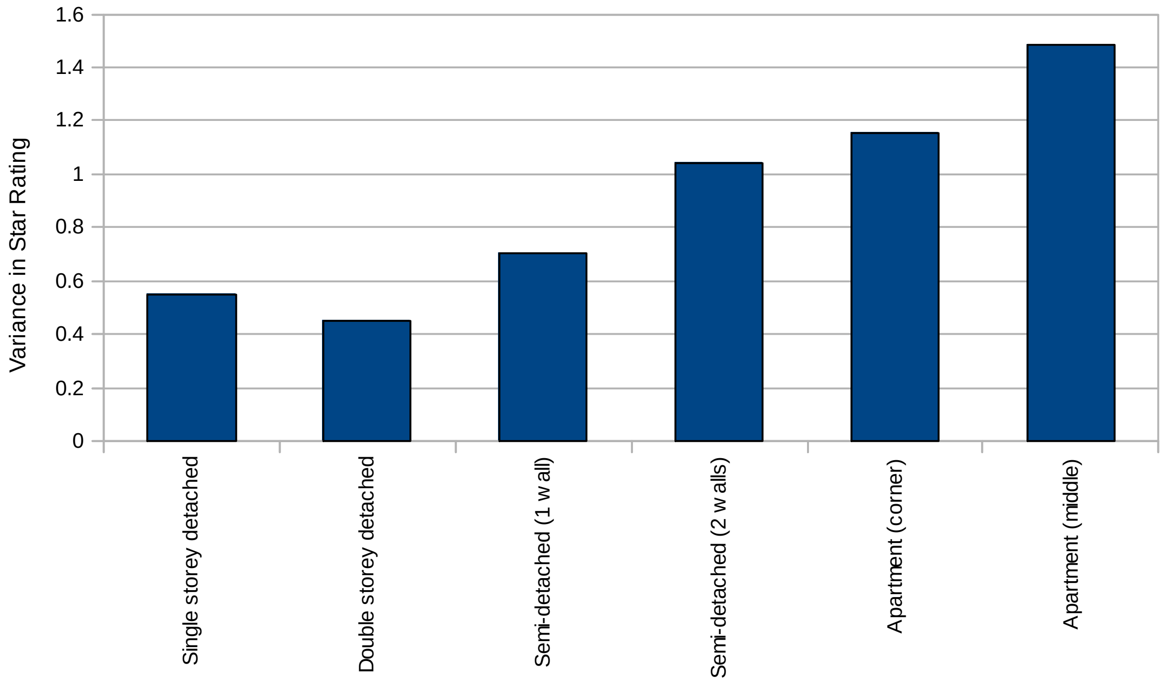

Figure 3: Variance in star rating due to orientation for original designs averaged by dwelling type.

Performance of Original Dwellings by Capital City

The study design set the initial rating requirement for Adelaide and Canberra to 6 stars and the rest of the capital cities to 5 stars, reflecting the earlier introduction of the 6 star requirements to Adelaide and Canberra.

By averaging the star rating for the original designs by capital city (Figure 4), it was found that Brisbane consistently rated lower than any other location with an average of 4.9 stars. Adelaide and Canberra achieved a higher average star rating than other capital cities due to reasons highlighted above. Of the other capital cities that were required to meet 5 stars Hobart achieved the highest average star rating at 5.8 stars, while dwellings in Darwin, Perth, Sydney and Melbourne rated similarly at 5.4 to 5.6 stars.

To further explore these trends, the average maximum star rating was calculated for each capital city (Figure 5). Again Adelaide and Canberra achieved a higher average maximum star rating than the other capital cities for the same reason as detailed above. Unlike its average star rating Brisbane's average maximum rating was not lower than other capital cities which all generally reached 5.7 to 5.9 stars with the exception of Hobart, which again achieved the highest rating at 6.1 stars.

The significantly lower average star rating found in Brisbane was explained by the effect of orientation. By calculating the variance in star rating caused by orientation it was revealed that the average star rating varied by more than 1.6 stars in Brisbane whereas all other capital cities varied by 0.5 to 0.9 stars (Figure 6). The other temperate climate cities were more influenced by orientation than cities with more extreme (hot or cold) climates.

The pronounced effect of orientation in Brisbane could be attributed to smaller total heating and cooling loads than in other capital cities which results in smaller star-band widths. This implies that changes to orientation or specifications can have more dramatic effects on the star rating and emphasises the importance of considering orientation when designing dwellings in Brisbane.

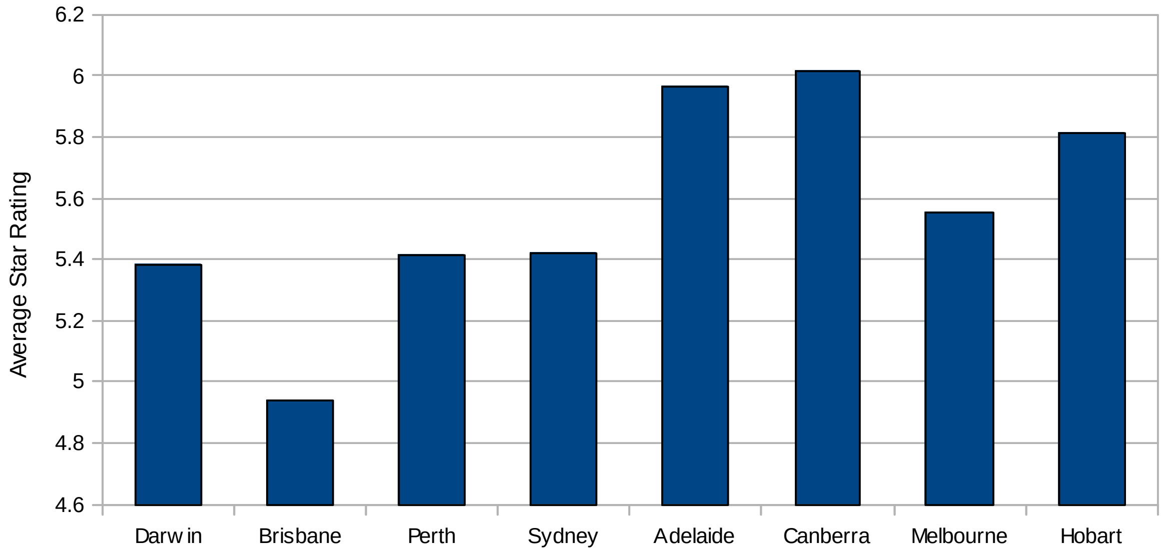

Figure 4: Average star rating for the original designs by capital city.

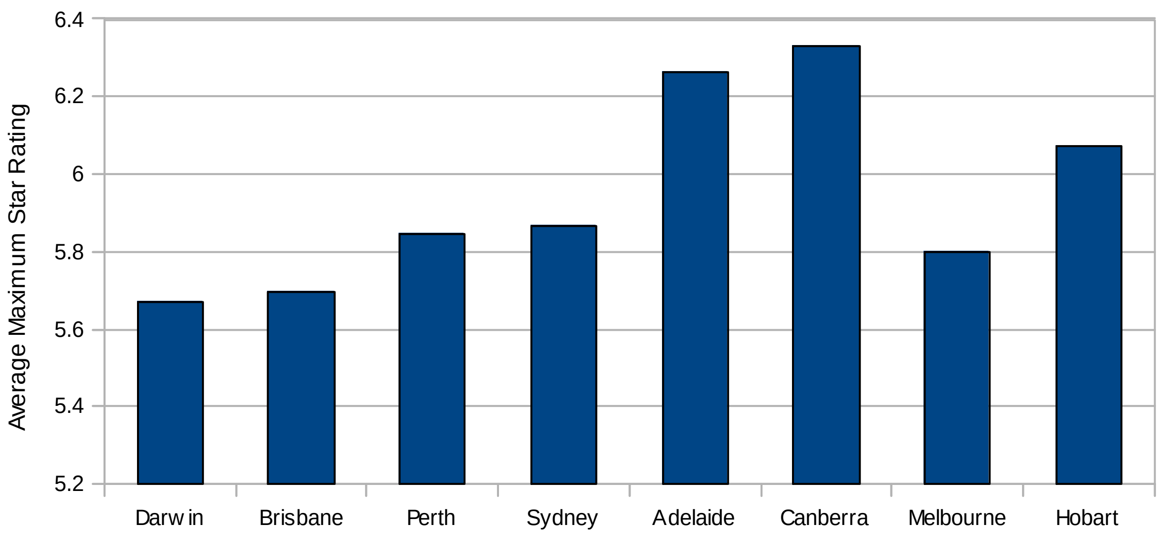

Figure 5: Average maximum star rating for the original designs by capital city.

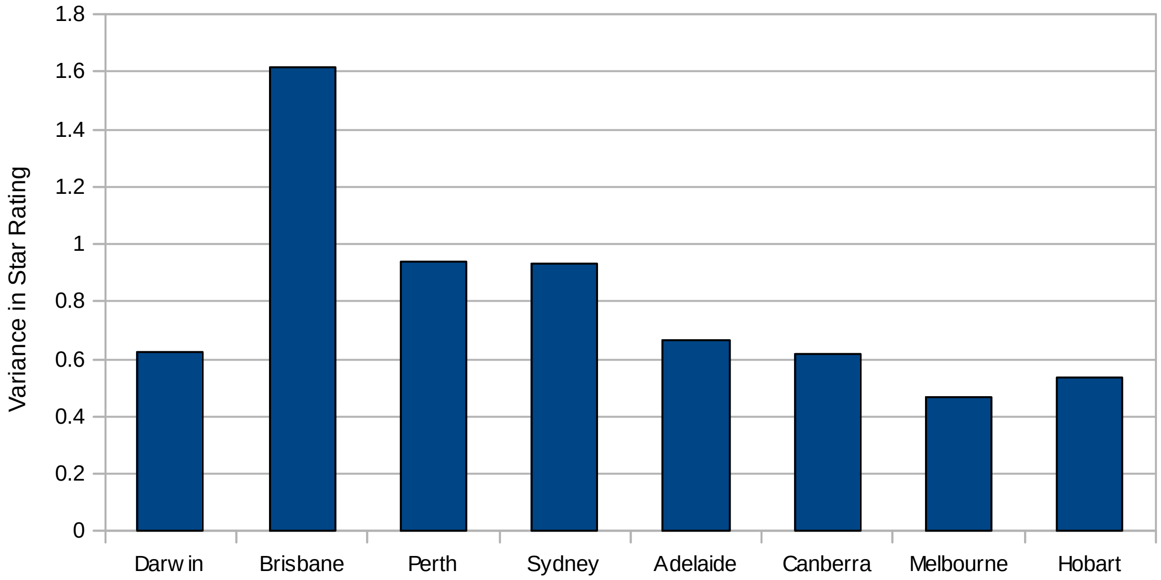

Figure 6: Variance in star rating due to orientations averaged for the original designs by capital city.

Performance of Redesigned Dwellings

For the vast majority of designs, this study found that it was possible to redesign dwellings to be more energy efficient and cost effective. For the 139 dwellings that were redesigned as part of this study the star rating was improved on average by one star. In conjunction with this star rating increase, an average cost saving of 1.6 per cent was achieved across all dwellings and locations.

The improvement was achieved through a combination of reorientation and design changes. The orientation selected for redesign was not always the optimal orientation. The orientation that was selected varied on average by 0.3 stars from the average star rating across all four orientations and included a combination of the best performing (62 dwelling locations), intermediate performing (34) and worst performing (43) orientations, while 21 dwelling locations were not redesigned due to the high performance for the original design.

The average star rating result for all redesigned dwellings (Figure 7) shows that, regardless of initial star rating for the original design, dwellings were effectively redesigned to achieve a rating above 6 stars. Most of the 20 dwellings were redesigned to achieve an average star rating between 6.1 and 6.5. A few dwellings averaged higher than this, the highest of which was Dwelling 20 at 6.9 stars.

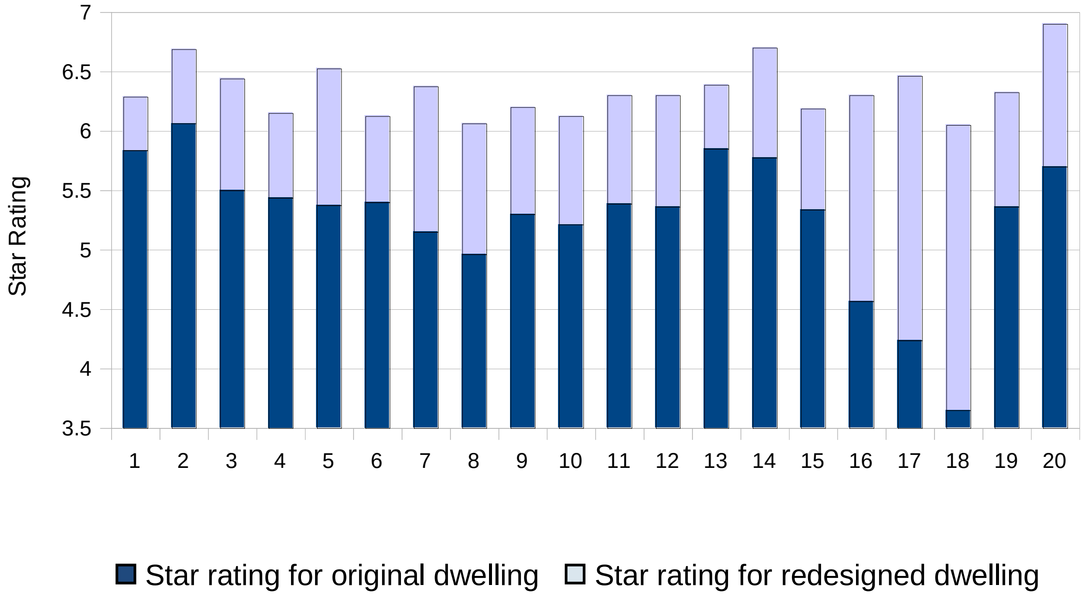

Figure 7: Star rating increase by dwelling as a result of redesign changes.

The average star rating change for each dwelling is presented in Figure 8 together with cost saving as a percentage. The graph shows that an average cost saving was achieved for all dwellings except for Dwellings 14, 17, 18 and 19. Two of these dwellings (17 and 18) were also associated with the highest star rating improvement despite increased costs. The highest average cost saving for an individual dwelling was for Dwelling 9 at nearly 4%.

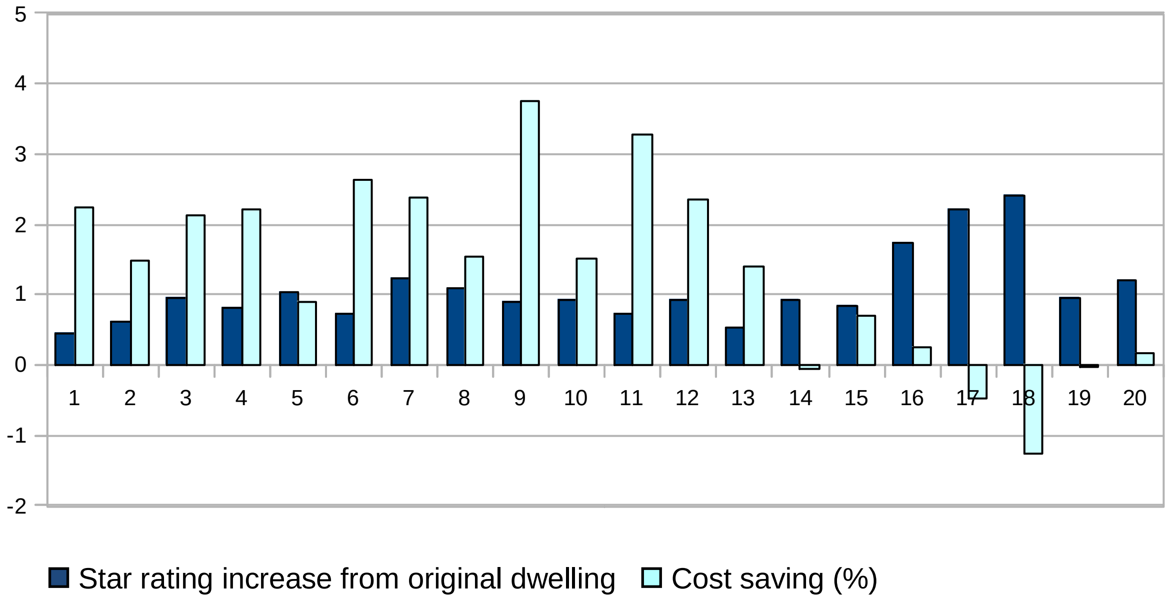

Figure 8: Average star rating change and cost saving (%) by dwelling as a result of redesign changes.

Performance of Redesigned Dwellings by Dwelling Type

Analysis of average star rating improvement by dwelling type revealed that corner apartments were improved by significantly more than the other dwelling types (Figure 9). Based on the orientation selected for redesign the average star rating for the original design was improved for corner apartments by 2.3 stars, while for other dwelling types the improvement was approximately one star or less.

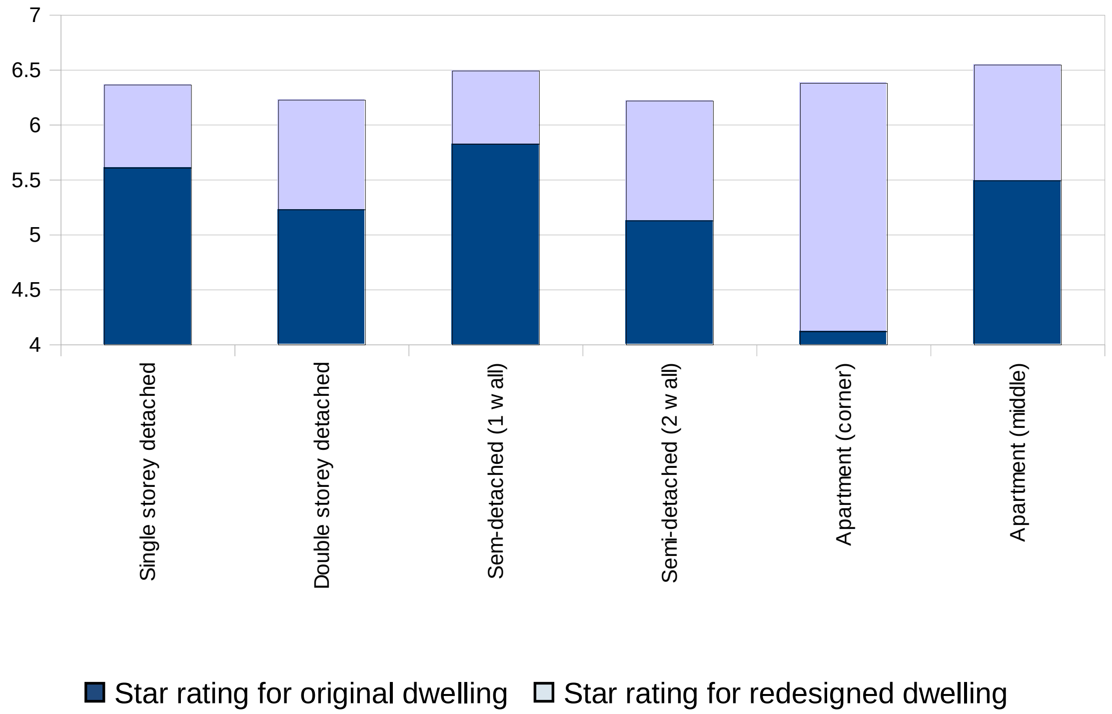

Figure 9: Star rating increase by dwelling type as a result of redesign changes.

The average star rating change and cost saving percentage was calculated by dwelling type to reveal that redesign of detached and semi-detached houses was associated with a cost saving, while apartments incurred a minor cost increase as a result of design changes (Figure 10). Cost saving trends were the same for broad categories of dwelling type, where detached houses (single and double storey) achieved the largest cost savings at 2 to 2.5%, semi-detached houses (one and two shared walls) achieved a moderate saving of 0.5 to1% and apartments (middle and corner) a marginal cost increase of 0.25%.

Redesign of all dwelling types was associated with an average star rating increase. However the apartments achieved the highest star rating improvement of any of the dwelling types of approximately 1.5 stars.

Increased costs incurred by the redesigned apartments can be partially explained by the reduction to glazing area for these dwellings which was replaced by more expensive concrete panelling. Any glazing changes to other dwelling types typically resulted in reduced construction costs as brick veneer provided a more cost effective material than some glazing units.

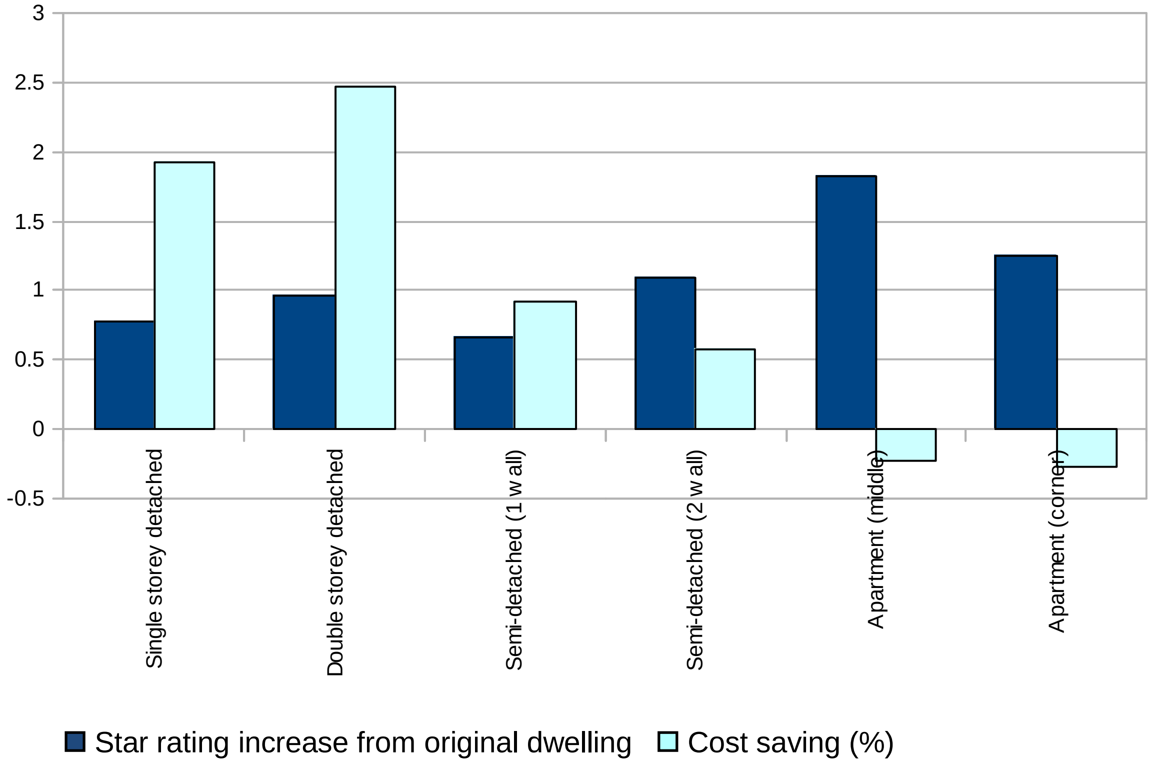

Figure 10: Average star rating change and cost saving (%) by dwelling type as a result of redesign changes.

Performance of Redesigned Dwellings by Capital City

In all capital cities dwellings were redesigned to achieve a star rating of 6.2 to 6.4, except in Hobart where dwellings achieved a star rating of 6.6 (Figure 11). For redesigned dwellings to achieve a similar star rating across all capital cities, average star rating was increased by 1.7 stars in Brisbane, 0.4 stars in Adelaide and Canberra, and approximately one star in all other locations. For the 5 star locations (all except Adelaide and Canberra) the average star rating improvement was 1.2 stars which was associated with a 1.3% cost saving. For the cities where the original design achieved 6 stars the star rating was improved by 0.4 stars which was associated with a 2.4% cost saving.

In Adelaide and Canberra the smaller star rating improvement was associated with the largest cost savings of 2.2 and 2.6% respectively (Figure 12). Brisbane, where the largest average star rating was achieved, was not associated with the smallest cost saving. In fact for a 1.7 star rating increase dwellings in Brisbane averaged a 1.5% cost saving, similar to Perth and Sydney. Cost savings in Melbourne and Hobart were slightly lower than this at 1.2%, and the lowest cost saving was in Darwin at 0.9%.

A complete summary of the average star rating change and cost saving (%) for each capital city and dwelling is provided in Appendix 1.

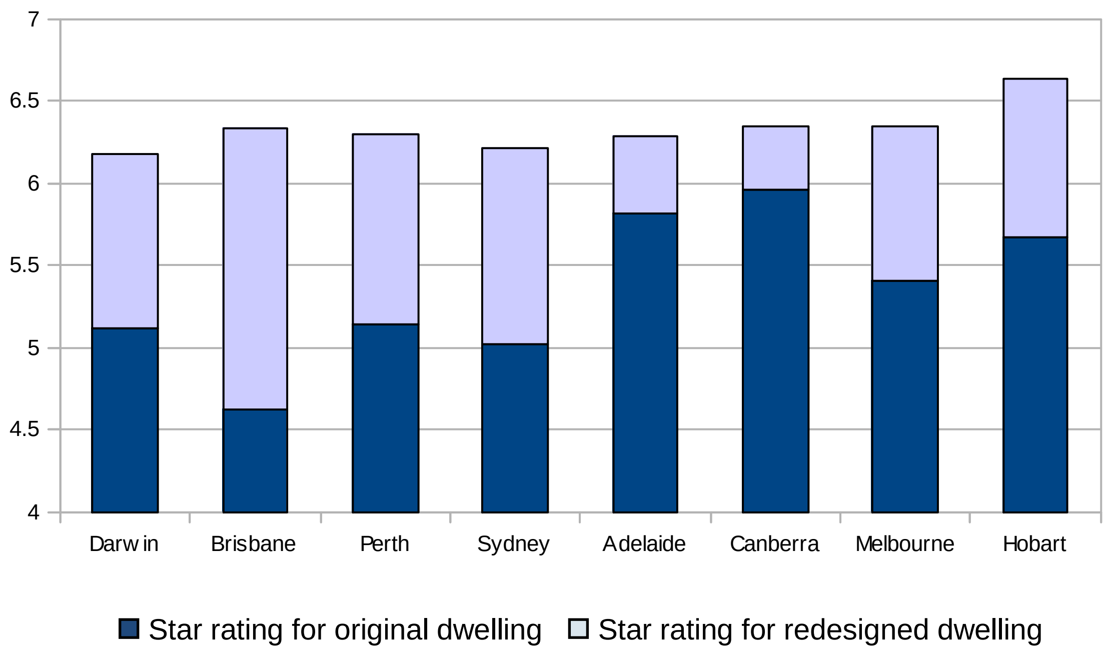

Figure 11: Star rating increase by capital city as a result of redesign changes.

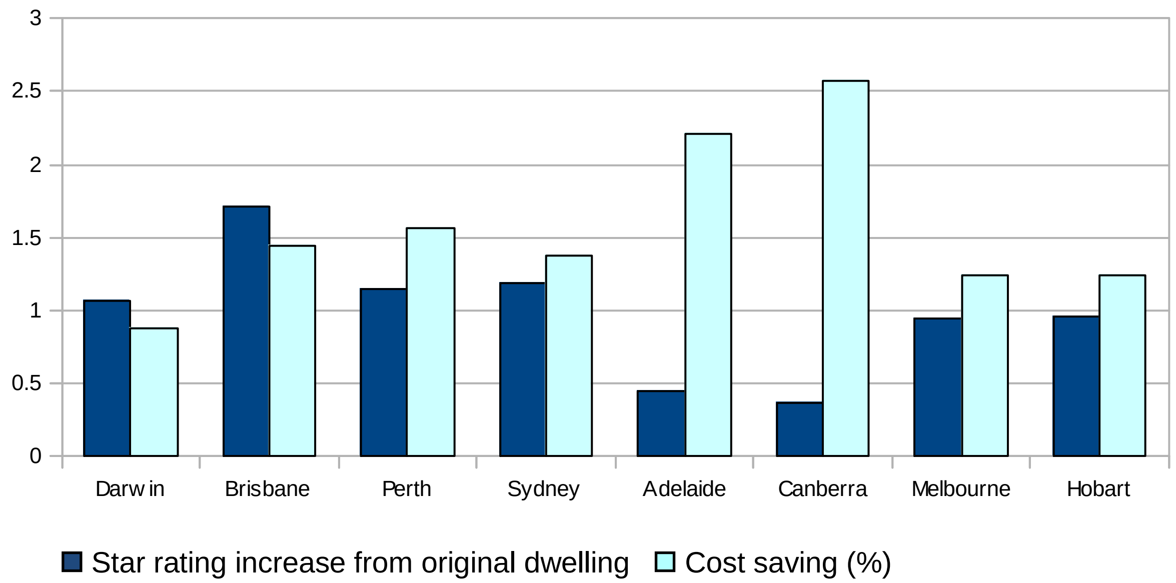

Figure 12: Average star rating change and cost saving (%) by capital city as a result of redesign changes.

Window to Floor Area Ratio

As part of the redesign, the window to floor area ratio was reduced on average across all dwelling types, as shown in Figure 13. The graph shows that for the single and double story detached houses and semi-detached houses with one shared wall window areas were reduced by approximately 2% on average. For the apartments and semi-detached houses with two shared walls the window to floor area ratio was reduced by closer to 7%.

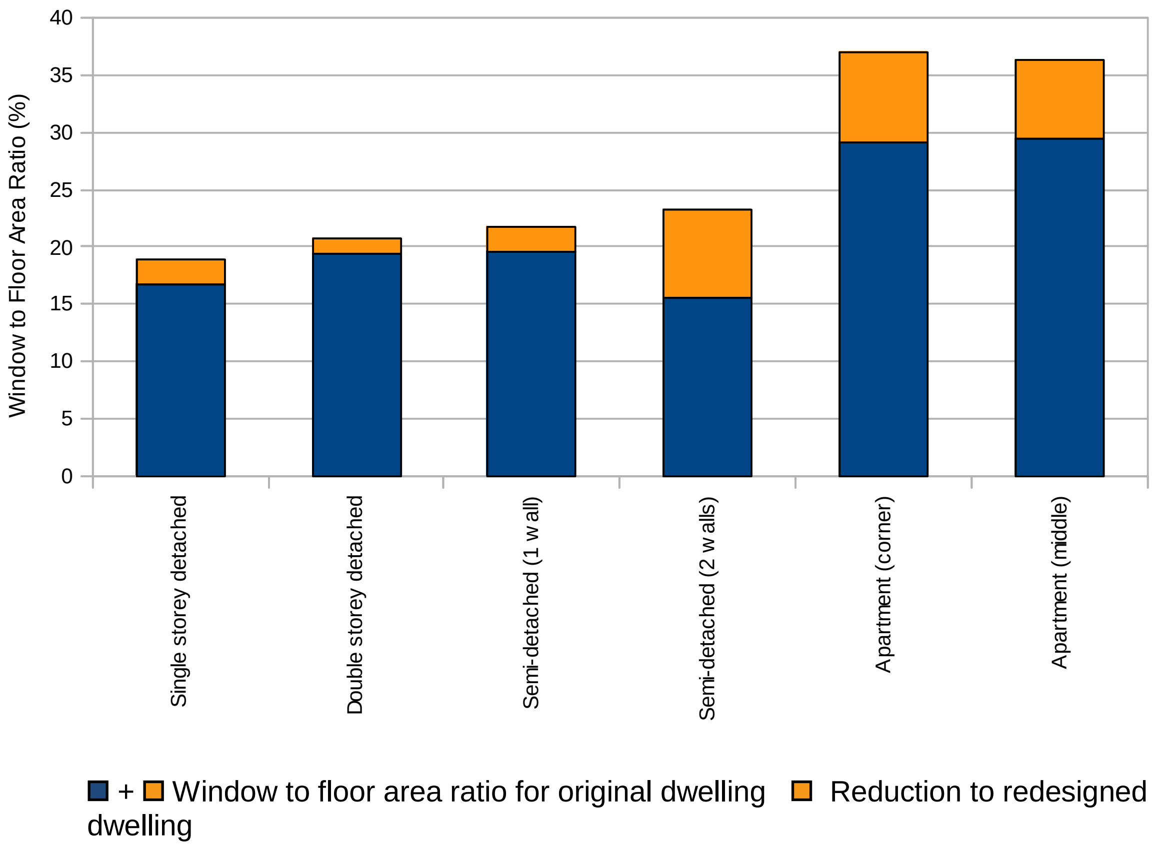

Figure 13: Window to floor area ratio by dwelling type for the original design and reduction due to redesign.

The average window to floor area ratio for original designs was the same across all capital cities. As a result of the redesign process, the window to floor area ratio was reduced by 2 to 3%, with a slightly higher reduction in Perth and lower reduction in Adelaide than in other locations.

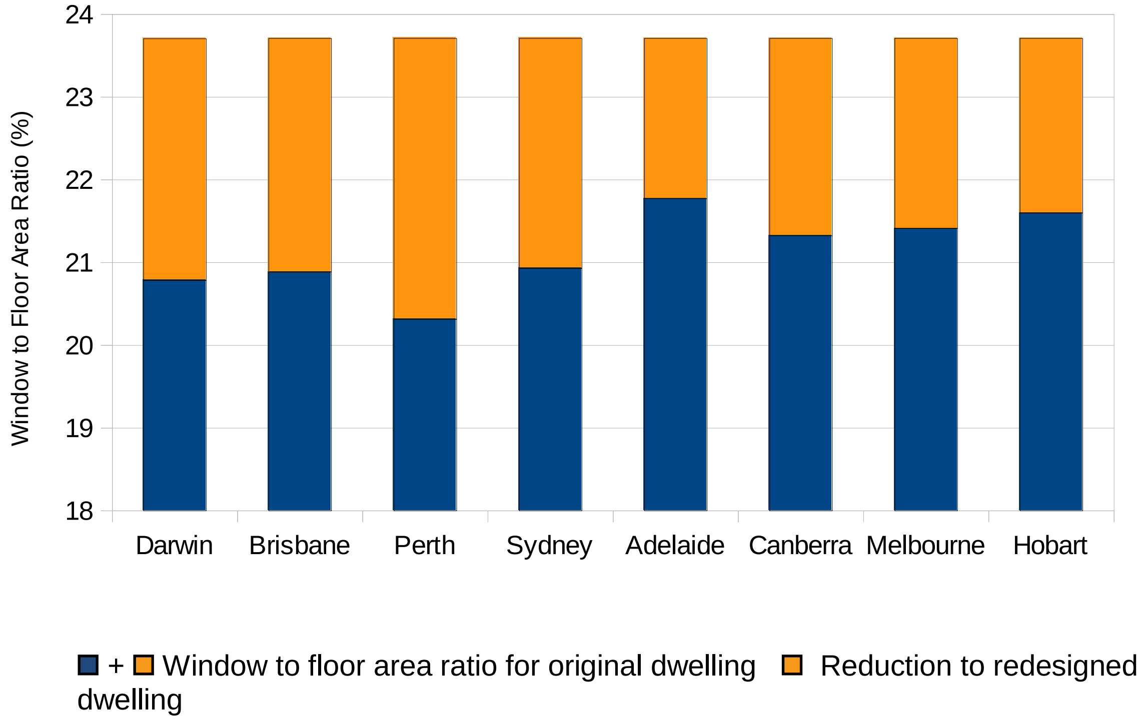

Figure 14: Window to floor area ratio by capital city for the original design and reduction due to redesign.

Case Study 1: Internal Room Layout and Zoning

Internal room layout - the placement of rooms within a dwelling - can have a significant impact on star rating, particularly when considered in conjunction with orientation. In addition to this, zone classification and whether an area is considered as a conditioned (has mechanical heating or cooling applied) or an unconditioned zone in rating software can also influence star rating.

Across all climate types daytime occupied zones (rooms which are expected to be heated or cooled between 7 am and midnight), such as living areas and kitchens, are more influenced by internal room layout and orientation than night-time occupied zones, such as bedrooms. This is because daytime occupied zones have a much longer occupancy schedule and higher heating requirements than night-time occupied zones and they can therefore account for a greater proportion of heating and cooling loads. Consequently in terms of energy efficiency rating it can be useful to pay particular attention to daytime occupied zones when designing dwellings.

In this study there are a number of examples of methods to improve star rating by optimising design for daytime occupied zones. One such method is to optimise the orientation of daytime occupied zones by climate type, as detailed below.

In hot and temperate climates with very high cooling loads and negligible heating loads the daytime occupied zones were relocated to the south with a thermal buffer provided by unconditioned or night-time occupied zones to the north, east or west. In this way the cooling load was reduced in the redesign of several dwellings, as illustrated by the example below for the single storey detached house Dwelling 5. This design change improved the star rating of Dwelling 5 in Perth by 0.6 stars and even in Adelaide - the coolest temperate city - the star rating was improved by 0.4 stars. In both cases the heating load increased slightly, but the cooling load was reduced by about 25%. It should be noted that potential benefits from orienting living areas south should be considered on a case-by-case basis, particularly for the cooler temperate climates which can significantly benefit from the passive solar benefits of north facing living areas. In this particular case the dwelling was not designed with summer shading.

In more typically temperate and cold climate types, north facing daytime occupied zones facilitates passive heating, as exemplified by several of the redesigned dwellings including Dwelling 6, a single storey detached house. It should be noted that benefits of passive heating to north facing living areas were only seen when combined with north facing windows.

Star rating can also be improved by locating living areas on the ground floor rather than the upper level of two storey dwellings, as illustrated by the redesign of Dwelling 10. As a two storey detached house, the original design included a living area and kitchen encompassing the entire upper floor with bedrooms located on the ground floor. However when daytime occupied zones are located on the upper level they do not receive passive heating and cooling benefits from the concrete slab on ground floor. Instead daytime occupied zones require more energy for heating and cooling which can result in a poor star rating.

During the redesign process for Dwelling 10 the daytime occupied zones were relocated downstairs and night-time occupied bedrooms and ensuite were relocated upstairs. By redesigning Dwelling 10 in this way, the star rating was improved most dramatically in hot and temperate climates, with a 0.7 star increase in Darwin and Adelaide (refer to Figure 15). The relocation of internal zones improved the star rating by a lesser extent in the cold climates, increasing the star rating by 0.3 stars in Canberra.

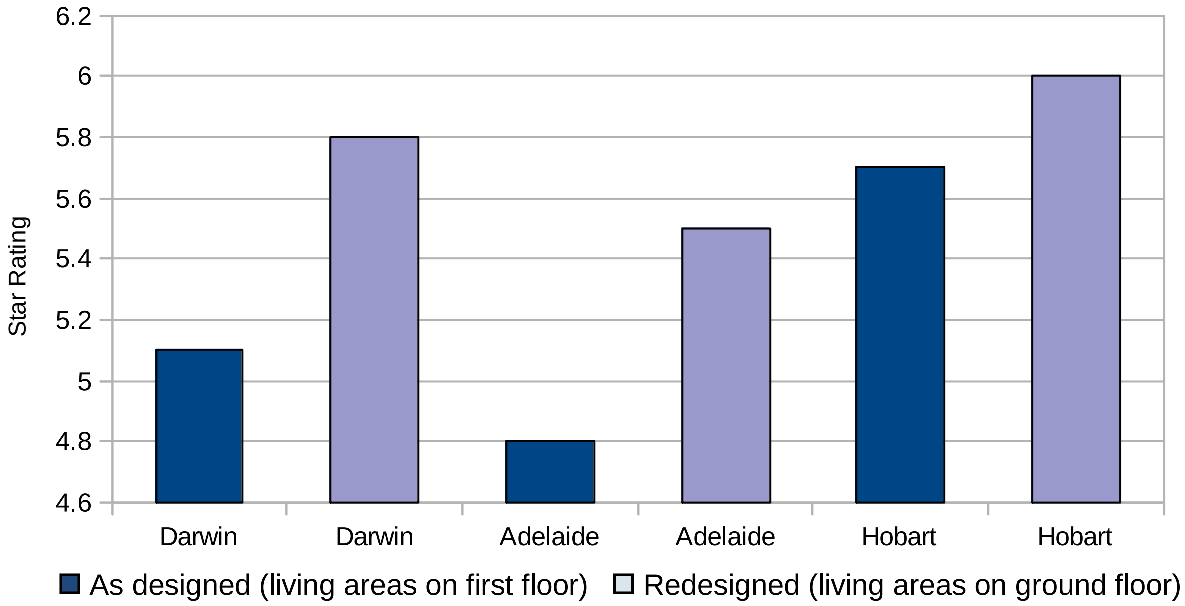

Figure 15: Star rating change for a double storey detached house (Dwelling 10) as designed with living areas on the upper level and bedrooms on the ground level compared to as redesigned with living areas on the ground level and bedrooms on the upper level in three capital cities which represent the three climate types in this study.

Another method used in this study to improve star rating through room layout changes involved grouping unconditioned zones together and insulating internal walls adjoining conditioned zones. Heating and cooling can leak from conditioned to unconditioned areas and by grouping these zone types together this effect can be reduced. This approach was employed in the redesign of a double storey detached house (Dwelling 8) where the laundry and toilet were grouped together and the internal walls adjoining the conditioned space were insulated in some cities. Designing in this way can also provide a cost effective way to minimise the amount of internal wall insulation required.

In addition to room layout changes, zoning changes were effectively used to improve the star rating of many of the dwellings through the use of internal doors. By adding internal doors or walls, corridors were changed from conditioned to unconditioned zones for many of the redesigned dwellings in this study, thereby reducing the total air conditioning loads. One such example of this was from a double storey detached house (Dwelling 12) which originally had 56m² of conditioned corridors, or almost 15% of the internal floor area excluding the garage. Converting this space into an unconditioned zone through the use of internal partitions and doors reduced the heating and cooling load substantially across all climates, particularly the temperate climates as displayed in Figure 16.

As expected, the addition of internal doors to separate unconditioned corridors from conditioned spaces reduced both the heating and cooling loads in all temperate and cold climates. The benefit of this design change was most pronounced in Brisbane where the star rating improved by 2 stars as a result of this change alone. In the other temperate climates this alteration increased star rating by 0.9 to 1.4 stars while the improvement in all cold climates was 0.5 stars.

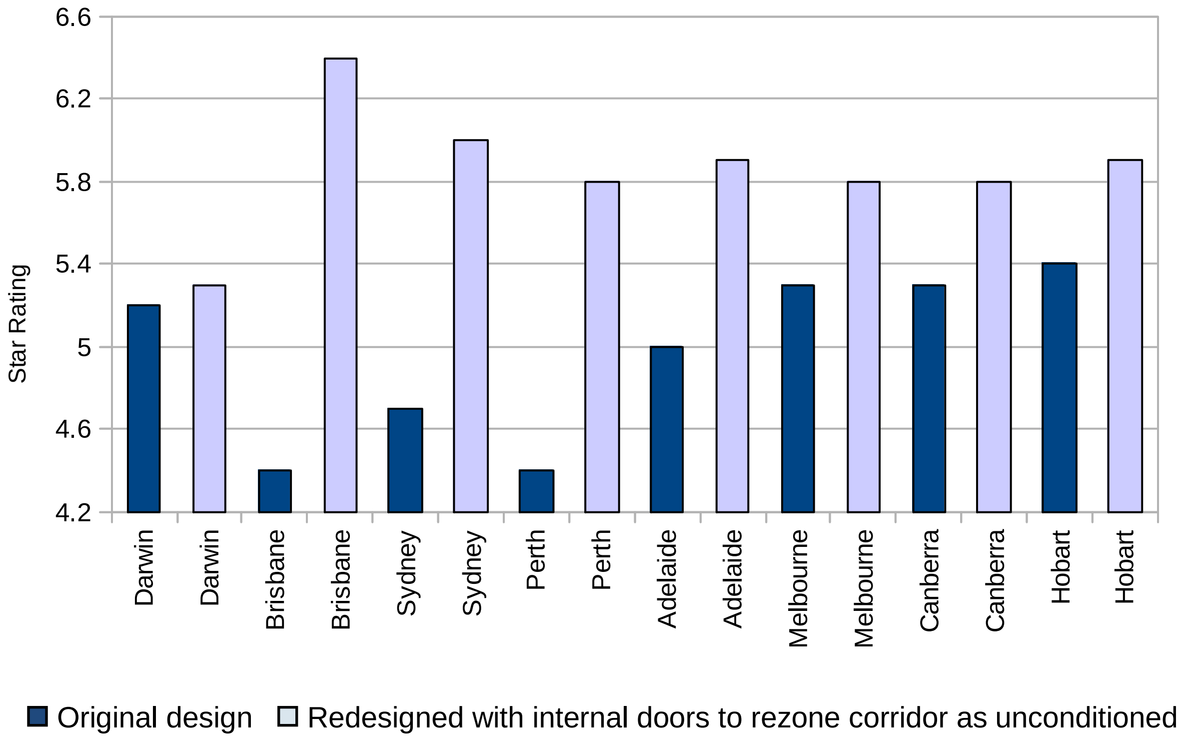

Figure 16: Star rating in all capital cities for a double storey detached house (Dwelling 12) illustrating the impact of using internal doors to rezone 56m2 of corridor as unconditioned space.

In reality there are other factors to consider when building a house other than energy efficiency, such as location of living areas to optimise views, desires of home owner and functionality. However changes to internal room layout and zoning often would not interfere with other considerations so they can be an easy way to improve star rating without compromising other design features. Optimising internal room layout and zoning at the design stage generally provides no-net-cost changes, making these very cost effective options to improve thermal performance of residential dwellings.

Case Study 2: Glazing Area and Orientation

Glazing area and orientation of glazing are two of the most important factors to consider when designing for energy efficiency. However when it comes to designing glazing area and orientation there are frequently conflicting priorities such as block orientation, views, privacy and other aesthetic considerations, these issues are highlighted by the residential builders in this study (see *Results: High Volume Residential Builder Survey – Summary of Responses*).

In terms of glazing area, most of the 20 original designs assessed in this study were designed with very reasonable amounts of glazing with a window to floor area ratio of around 20%. The apartments and one of the semi-detached houses were designed with higher amounts of glazing with a window to floor area ratio of around 35%. Despite this, results showed that several dwellings with low window to floor area ratios rated quite poorly while some of the apartments with high window to floor area ratios rated highly, indicating that window to floor area ratio alone is not the most important factor when it comes to glazing design and thermal performance.

The heating and cooling loads of daytime occupied zones can have a larger impact on the star rating than other zone types and excessive glazing to these zones can cause problems for thermal performance. This is illustrated by a single storey semi-detached house with two shared walls (Dwelling 15) which was originally designed with a window to floor area ratio of 32%. The original design rated very poorly requiring high performance glazing to meet the minimum required star rating. To overcome the glazing limitation provided by two shared walls this dwelling contained two internal courtyards, the larger of which was comprised almost entirely of glazing that adjoined the living zones. Although this glazing would receive virtually no direct sunlight which would cause passive heating issues in hot and temperate climates, the large area of glazing provided little insulating effect and facilitated excessive heat loss and gain causing thermal performance issues across all climate types. To alleviate this issue, this dwelling was redesigned to reduce the window to floor area ratio from 32 to 20%, or a total window area reduction of 37%. This was the highest percentage glazing reduction due to redesign for any dwelling in this study, but in this way the glazing type was reduced to standard 3mm clear whilst improving the star rating significantly across most climates.

Orientation of glazing can have a considerable effect on star rating. Typically east and west facing glazing can cause star rating problems for buildings with a high cooling load by elevating the amount of direct sunlight into a dwelling. These effects are most pronounced in daytime occupied zones which account for a large proportion of the total cooling load. In contrast, north facing windows can have a beneficial impact by facilitating passive heating in temperate and cold climates and, when teamed with adequate shading, can prevent direct sunlight in summer in hot and temperate climates. Similarly in hot climates south facing windows limit direct sunlight, although in cold climates they provide no benefits from passive heating. Many dwellings were redesigned in this study in accordance with these principles, including a single storey dwelling (Dwelling 1).

In terms of construction costs, optimising orientation of glazing provides a no-net-cost design change. In fact the star rating benefit associated with this type of design change actually provides a cost benefit by reducing the need for high performance glazing in many instances. Reducing glazing area to a moderate amount of 20 to 25% can also reduce construction costs, dependent on wall construction types. For apartments, which are generally constructed of concrete, a reduction in glazing generally incurs marginally increased costs. As demonstrated in this study, apartments tend to be strongly influenced by orientation and the associated glazing effects so applying conservative amounts of glazing can improve star rating for little cost increase in these cases.

Case Study 3: Roof Colour

Variation to roof colour between light, medium and dark, with solar absorptance of 30, 50 and 85 per cent respectively, was assessed in each of the capital cities. It was found that roof colour generally had a significant impact on the thermal performance of dwellings in most capital cities. The addition of reflective foil, as a form of roof insulation, reduced the effect of solar absorptance although there was still some benefit from roof colour in most capital cities.

Figure 17 shows the effect of roof colour on star rating for a single storey detached house (Dwelling 2) when the dwelling had R3.5 ceiling insulation but no roof insulation, as well as the comparative effect of roof colour when the dwelling was also fitted with reflective foil to the roof. For Sydney and Adelaide, it can be seen that when this dwelling had no roof insulation it achieved a lower star rating with a dark roof (85%) but achieved the same star rating with a light (30%) and medium (50%) coloured roof. However when reflective foil was added to the roof the effect of roof colour was nullified so that the dwelling achieved the same star rating with all three roof colours. In Darwin, Brisbane and Perth this dwelling scored the highest star rating with a light roof colour, irrespective of whether there was reflective foil to the roof or not. The inverse was true in the three cold climate cities where this dwelling performed best with a dark roof colour with the presence or absence of reflective foil to the roof.

Dwelling 2 provides just one case study and throughout the study it was found that the effect of roof colour in different capital cities varied for different designs or dwelling types. However this example does provide a general indication of the comparative effect of roof colour across different climates. Within the study there were also a number of dwellings in Adelaide and Sydney that achieved a higher star rating with a light roof colour, where a medium coloured roof performed best in Canberra, or where a range of colours were optimal in the temperate and cold climates.

A case study to explore the effect of roof colour on a double storey detached house (Dwelling 8) is also provided (Figure 18). In this example variation to roof colour had an overall reduced effect on star rating, either with or without a form of roof insulation, when compared to the case study findings for the single storey detached house.

A possible reason for this is that as a two storey dwelling with the majority of daytime occupied zones located on the ground floor, the roof space primarily adjoined bedrooms and unconditioned bathrooms. In addition to this, the roof space only directly affects the upper level zones, or half of the total floor area. As such any changes to the roof zone might be negated for a two storey compared to a single storey house. The fact that the benefit of reflective foil to the roof was significantly less than for the double storey house compared to the single storey house also supports this theory.

Optimising roof colour for different climates and designs provides a no-net-cost design change which can have dramatic effects on star rating. Results indicated that star rating could be increased by more than a star, compared to the worst performing colour, simply due to changing roof colour and consequently it should be considered in dwelling design and energy efficiency modelling where possible.

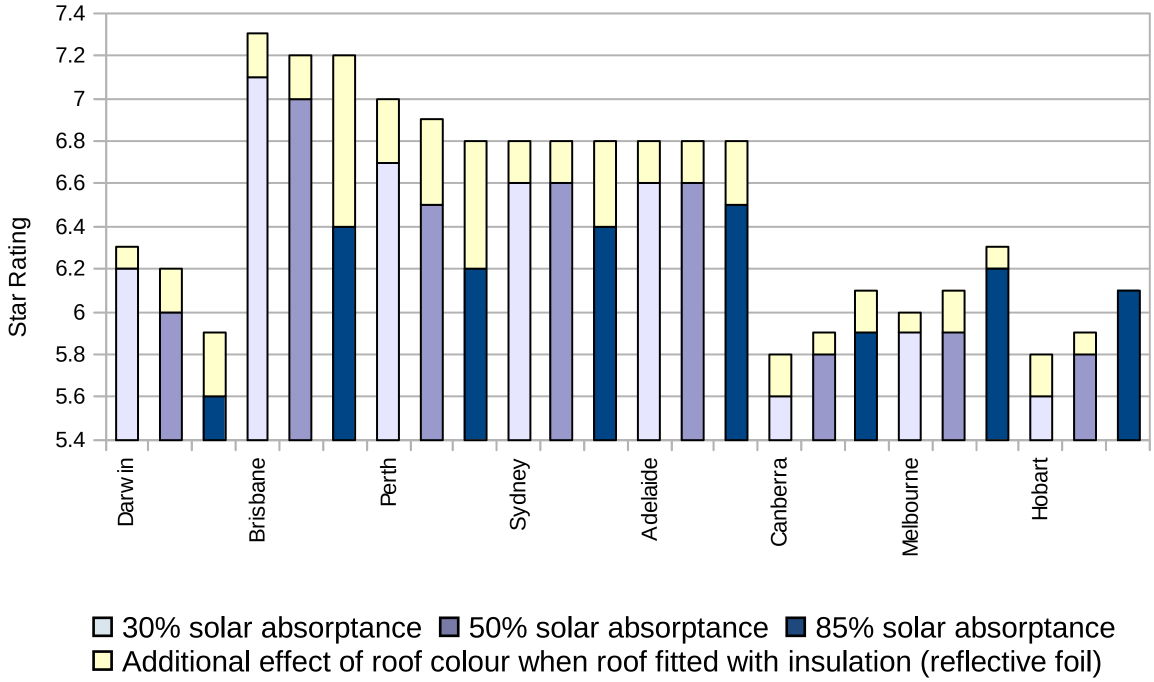

Figure 17: The comparative effect of roof colour when the roof has no form of insulation and with reflective foil to the roof on star rating for a single storey detached house (Dwelling 2) in each capital city.

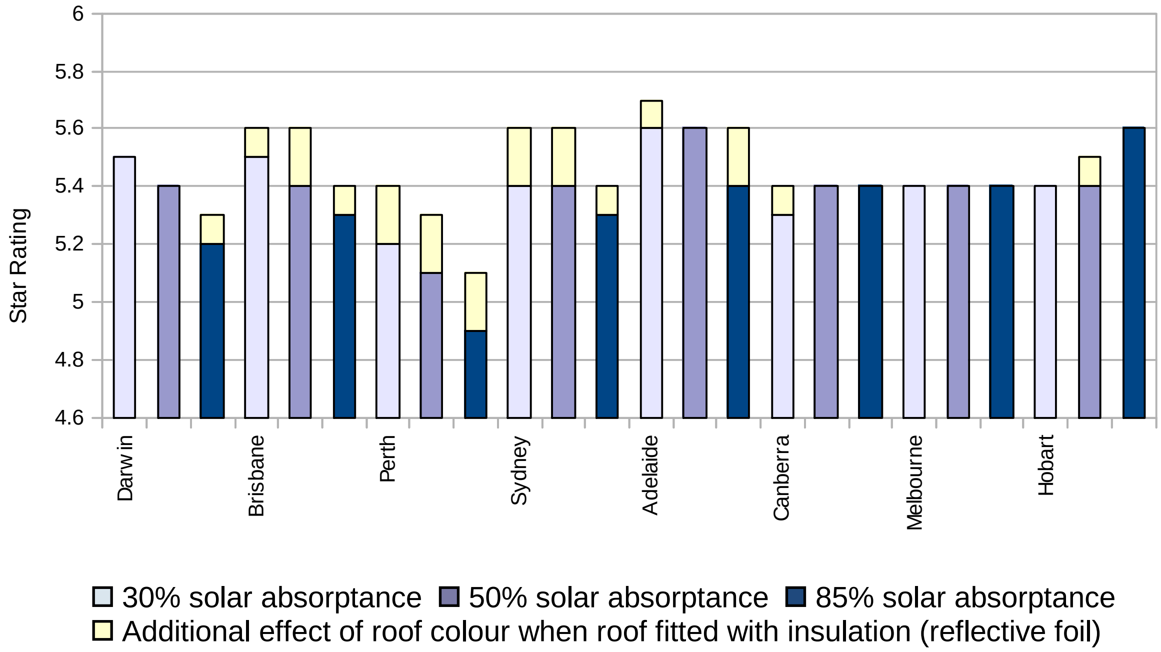

Figure 18: The comparative effect of roof colour, when the roof has no form of insulation and with reflective foil to the roof, on star rating for a double storey detached house (Dwelling 8) in each capital city.

Case Study 4: Insulating Concrete Slab on Ground and Variation of Floor Coverings

Another redesign change explored by the study was the effect of insulating CSOG using a polystyrene core (such as a Waffle Pod http://www.wafflepod.com). It was found that for all dwelling types (excluding apartments where this effect was not assessed) the star rating increased significantly for all designs in Canberra, Melbourne and Hobart when polystyrene core was added to a concrete slab on ground. Star rating typically increased the most in Hobart and to a lesser extent in Canberra, by about 0.8 and 0.5 stars respectively. This significant star rating increase was also associated with a no-net cost increase according to data provided by the quantity surveyor Davis Langdon and as such provided a very effective redesign option in cold climates.

For the other climate types, the effect of polystyrene core concrete slab compared to uninsulated concrete slab on ground varied between no change and a slight star rating decrease. In the cooler temperate climate cities (Adelaide and Sydney) there was also a slight star rating increase for at least one dwelling in combination with other factors, as illustrated below.

The effect of insulating concrete slabs was also explored in combination with variation to the floor covering type to the main living area using vinyl (Figure 19) or carpet (Figure 20). These two floor covering types provide different levels of above ground slab insulation. For the purpose of this study vinyl was selected as a hard floor covering as the most cost effective redesign option however it was also found that polished concrete or floating timber floor would perform fairly similarly.

In this particular case study example for a single storey detached house (Dwelling 2), with a vinyl floor to the living area the hot and temperate climate cities performed worse with an insulated concrete slab floor. When the main living area had a carpet floor covering all climates except for Brisbane performed the same or slightly better with polystyrene core concrete slab than without this insulation. This case study provides an unexpected result for this dwelling, and this example highlights the need for further investigation to better understand the combined effects of polystyrene core concrete and variable floor coverings in different climates.

A second case study example for the effects of concrete slab and floor coverings in a double storey house is also provided (Figures 21 & 22). Across all capital cities the carpet floor covering reduced the effect of polystyrene core concrete compared to vinyl, as carpet provides a form of insulation against thermal benefits and effects of concrete slab. In this example, irrespective of floor covering type, polystyrene core concrete only improved the star rating in the cold climate cities. Interestingly, polystyrene core concrete actually performed 0.3 stars worse than uninsulated concrete in Adelaide.

The combined effect of floor covering types with concrete slab insulation provides an interesting factor to consider. However floor covering type is a highly variable factor which is not for the life of a building and as such there may be some issues with designing for the combined effects with other variables which would not be altered at a later stage, such as polystyrene core concrete.

The addition of polystyrene core to concrete slabs provides a no-net-cost design change and as such should be employed in the construction of all detached and semi-detached houses in Canberra, Melbourne, Hobart and other cold climate zones. Whilst there may be some cost increases associated with variable floor coverings, this study demonstrated that floor coverings can have a significant impact on star rating. As such they provide a cost effective design option relative to the thermal benefits that they can provide.

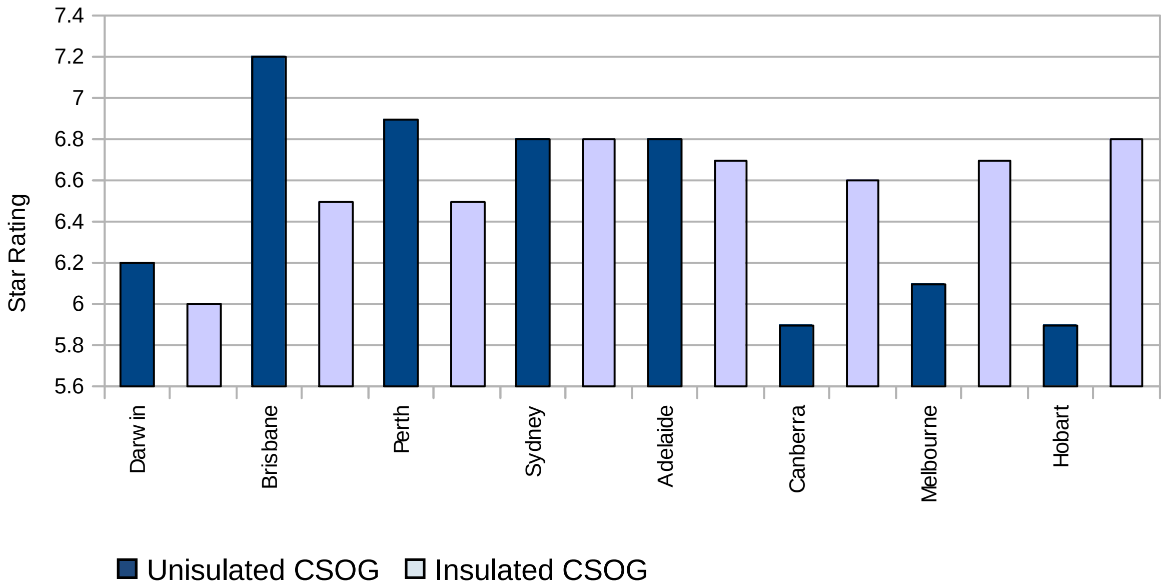

Figure 19: The effect of uninsulated and insulated CSOG on star rating for a single storey detached house (Dwelling 2) in each capital city, where the main living area has vinyl floor covering.

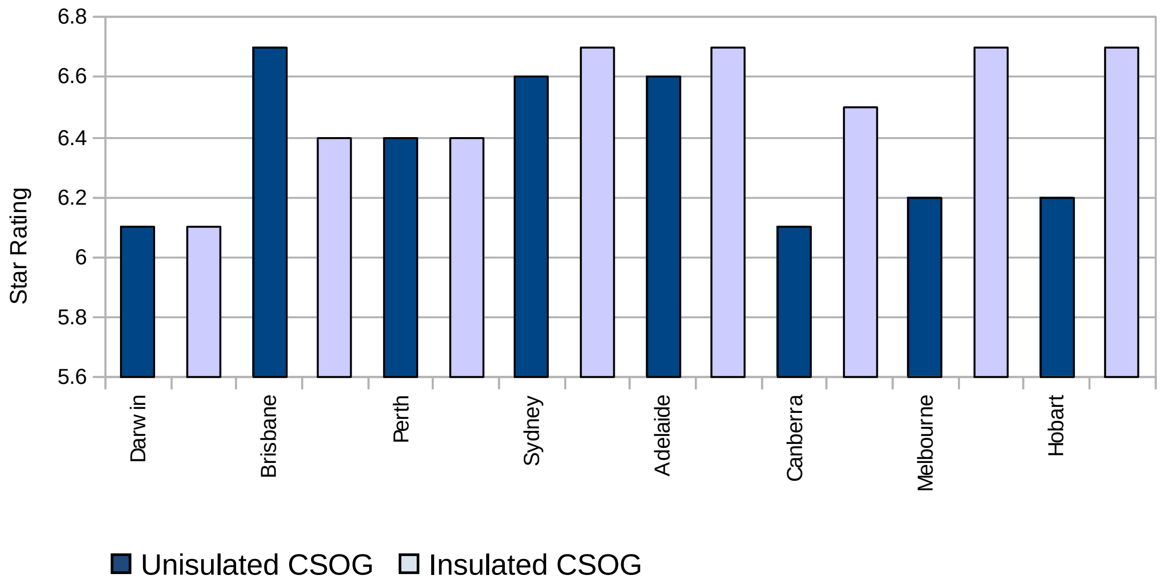

Figure 20: The effect of uninsulated and insulated CSOG on star rating for a single storey detached house (Dwelling 2) in each capital city, where the main living area has carpet floor covering.

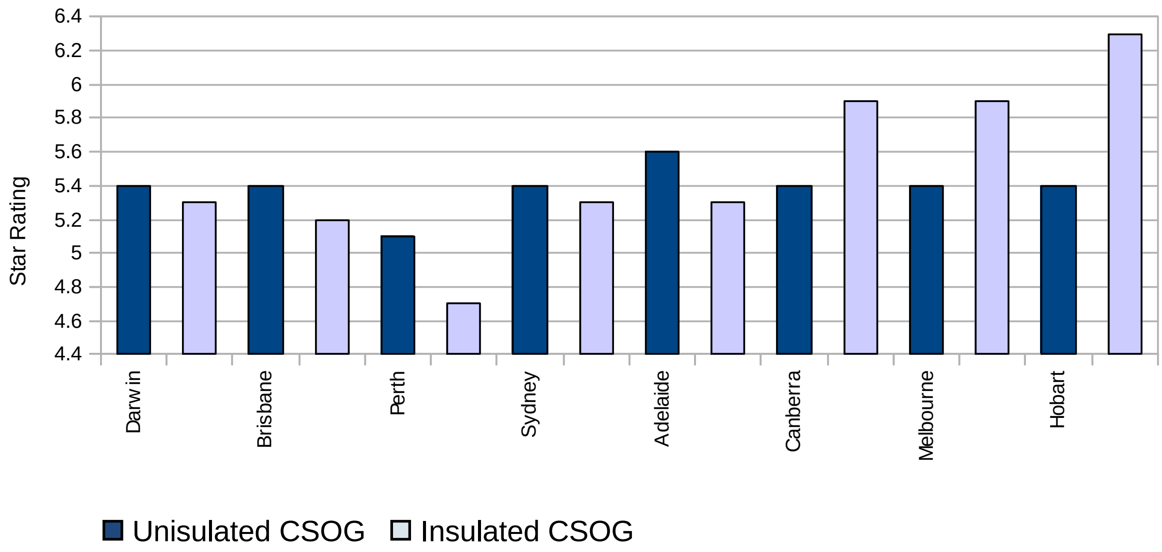

Figure 21: The effect of uninsulated and insulated CSOG on star rating for a double storey detached house (Dwelling 8) in each capital city, where the main living area has vinyl floor covering.

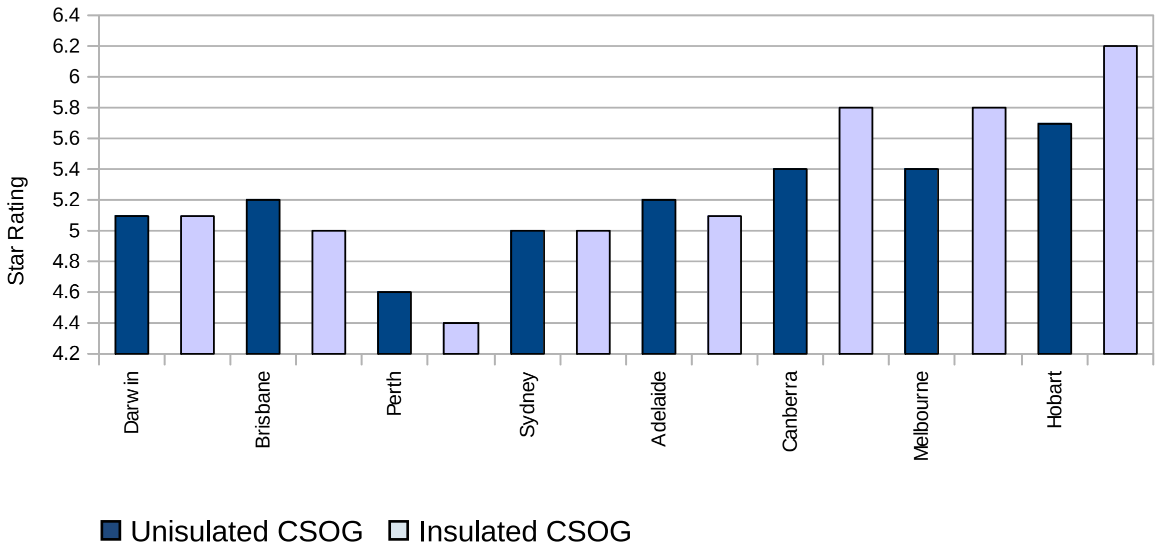

Figure 22: The effect of uninsulated and insulated CSOG on star rating for a double storey detached house (Dwelling 8) in each capital city, where the main living area has carpet floor covering.

Case Study 5: Shading

Several forms of shading were considered in this study: eave width, permanent or removable shading to outdoor living areas and awnings to windows. The later shading option was not typically used as part of the dwelling redesign in this study due to costs associated with roller shutters. There are cheaper alternative awning options available and awnings provide an effective energy improvement option, so we would recommend their consideration for use in hot and temperate climates.

Changes to eave width were frequently used in the redesign of dwellings in this study. Overall eave width was found to have a small effect on star rating. In the case study of a single storey detached house (Dwelling 2) with eaves around the entire dwelling, as presented in Figure 23, it can be seen that only in Perth, Sydney and Adelaide was effect of variable eaves negligible. In the other capital cities variation in eave width from none to 0.8m had a significant effect on star rating, where a wide eave achieved the highest star rating in Darwin and Brisbane and star rating was highest for dwellings without eaves in cold climate cities.

A different trend was found for a double storey detached house with variable eave width to the upper level only (Figure 24). In contrast to the single storey example, variable eave width had little effect in the cold climate cities and a significant effect in Perth and Sydney, as well as Adelaide to a lesser extent.

As with glazing area, the effect of eave width on dwelling energy efficiency also varies dependent on orientation. Higher energy efficiency levels and reduced construction costs could be achieved by optimising eave width for different facades, although this was not explored in this study.

Shading structures to the outdoor living area were varied for several of the redesigned dwellings in temperate and cold climates. The study found that star ratings could be slightly improved by replacing permanent roof structures to the outdoor living areas with removable shade sails. This change only had a minor effect on star rating except in the cold climates where it was generally found that star rating could be improved more by removing outdoor living area shading altogether. Outdoor living areas typically adjoin living areas with large glass sliding doors and windows. Removable shade sails were used to allow passive solar heating in the winter and to provide shading in summer.

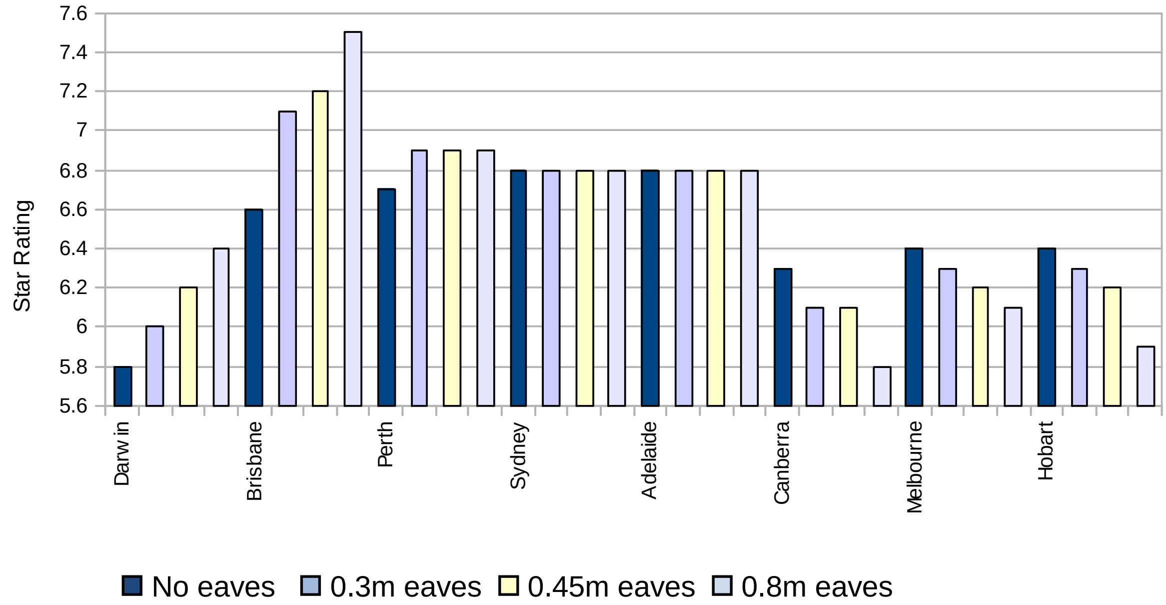

Figure 23: The effect of eave width on star rating for a single storey detached house (Dwelling 2) in each capital city.

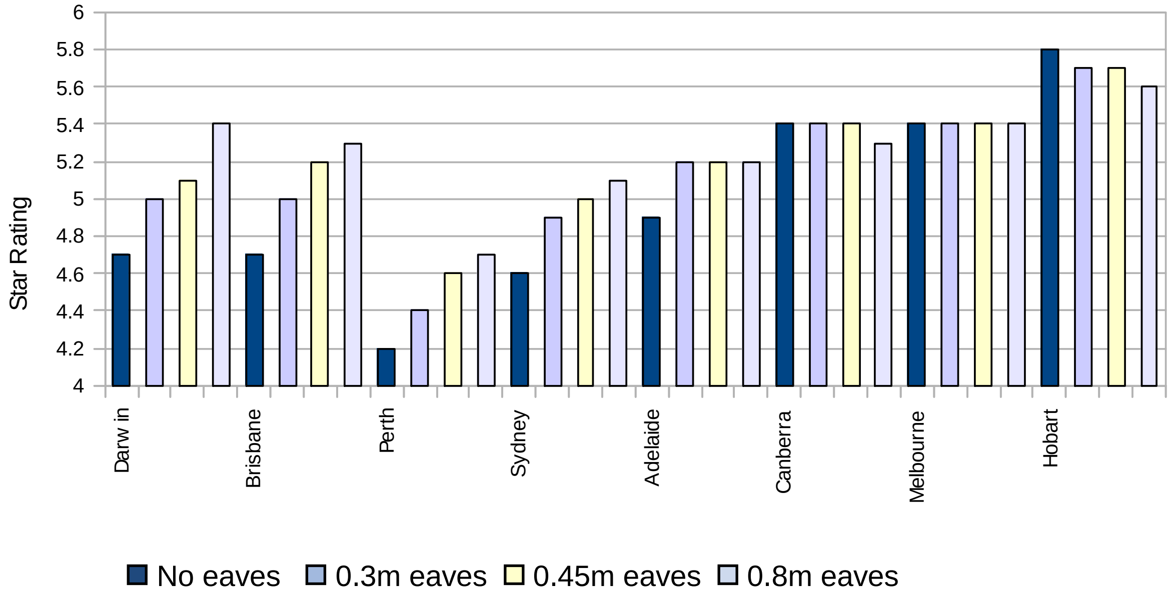

Figure 24: The effect of eave width on star rating for a double storey detached house (Dwelling 8) in each capital city.

Case Study 6: Ventilation

Dwellings in hot and, to a lesser extent, temperate climates benefit from increased ventilation to remove excess heat in warmer months. Methods to improve ventilation can include increasing the openable window area, ceiling fans, whirly birds to roof space and, where dwellings have a raised timber floor, an open sub-floor zone. All of these methods were used in this study with the exception of increasing the openable area of windows which was not undertaken due to increased costs associated with this.

In this study increased ventilation and air movement provided by ceiling fans improved star ratings most dramatically when added to daytime occupied zones, particularly the open plan kitchen/ living zones. The use of ceiling fans at opposite ends of dwellings also improved the star rating, as with Dwelling 4 in Darwin, Dwelling 6 in hot and temperate climate cities except Adelaide and several other dwellings. The effect of ceiling fans was most dramatic in Darwin and Brisbane. For example, the star rating of Dwelling 12 was improved by 0.3 stars by adding one ceiling fan to the main living area. For some dwellings there was also a benefit in the other temperate climates. A single ceiling fan was costed at $250 for the purpose of this study, and as such they provided a cost effective redesign option relative to associated thermal performance benefits.

Ventilation of the roof space through the use of whirlybirds improved the star rating across hot and temperate climates by reducing heat from the roof space. The star rating was improved by 0.3 stars in Darwin and 0.2 stars in Adelaide for Dwelling 4 as a result of ventilating the roof zone, although this provided an expensive redesign option for the purpose of this study.

Case Study 7: External Wall Construction and Variable Insulation Levels for Detached Houses

The typical construction type used for external walls of new homes is brick veneer across much of Australia and double brick in Perth, although lightweight construction is also used for some houses. To better understand the comparative effects of external wall construction type, a single storey detached house with concrete slab on ground floor was assessed with several wall construction types such as lightweight (FCS), brick veneer, reverse brick veneer and brick cavity and variable insulation levels from double foil to R2.5. The results from this analysis are presented below for Darwin, Perth and Melbourne only. Results for some locations also include higher levels of insulation to cavity brick than typically to investigate the theoretical thermal effects of brick cavity compared to other construction types.

The results for this dwelling in Darwin are provided in Figure 25. The graph shows that when the only type of wall insulation is double foil, lightweight wall construction performs almost 2 stars worse than cavity brick, while brick veneer and reverse brick veneer achieved the same star rating as each other. The comparison of wall construction types with R1.5 insulation revealed no or marginal difference in thermal performance. Higher levels of insulation indicated a similar result.

A comparison of brick veneer, reverse brick veneer and cavity brick with varying levels of insulation in Perth (Figure 26) revealed that with the same levels of insulation reverse brick veneer consistently performed better than brick veneer by 0.3 stars. Similarly, brick cavity with foil performed 0.6 stars better than reverse brick veneer with double foil. However when insulated with R1.5 or higher, there was virtually no difference in thermal performance between reverse brick veneer and cavity brick, assuming that cavity brick could be insulated to R1.5 and R2.

The results for Melbourne were very similar to Perth (Figure 27) and demonstrated that there would be a 0.3 star rating improvement associated with using reverse brick veneer rather than the typical brick veneer.

Reverse brick veneer provides a more cost effective construction method than cavity brick, whilst achieving similar thermal performance standards. Although reverse brick veneer provides a more expensive construction method than brick veneer, it is possible that reverse brick veneer construction costs could be more similar to brick veneer in the future if this construction method were adopted as standard practice.

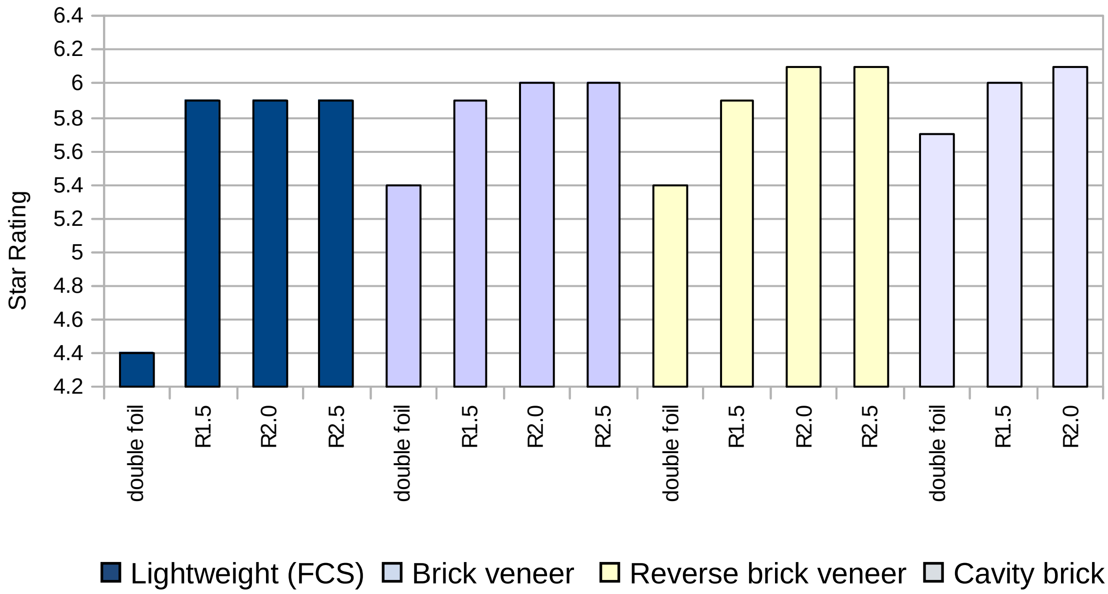

Figure 25: Comparison of the effect of wall construction and insulation on star rating for a single storey detached house (Dwelling 2) in Darwin.

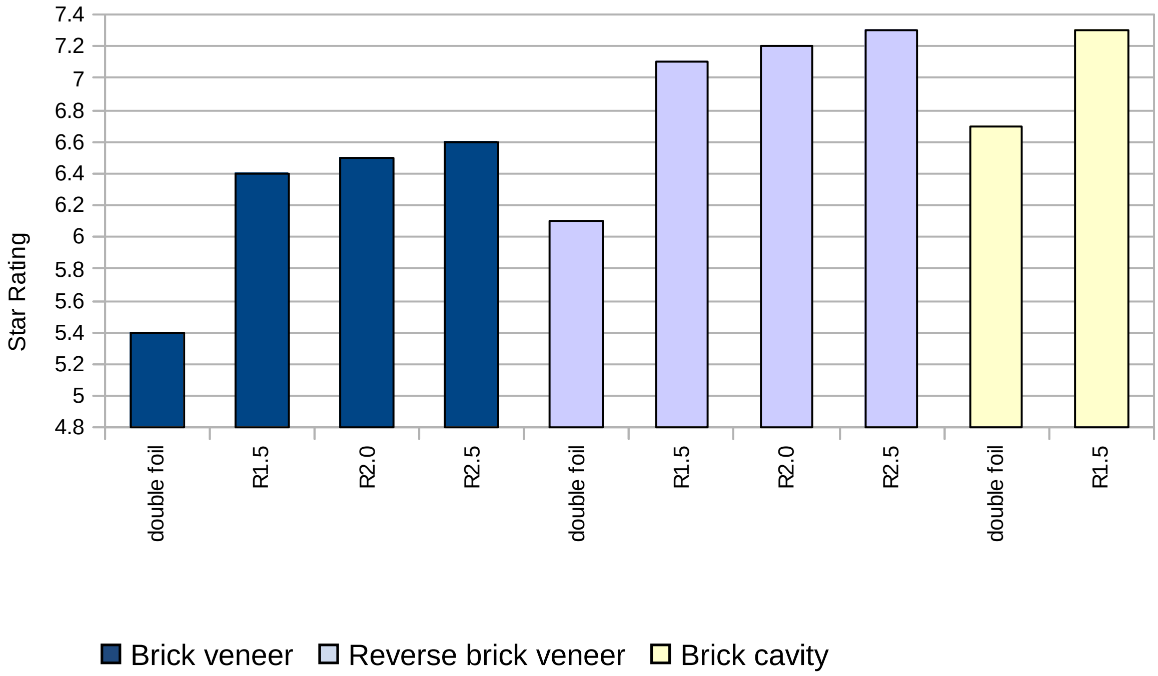

Figure 26: Comparison of the effect of wall construction and insulation on star rating for a single storey detached house (Dwelling 4) in Perth.

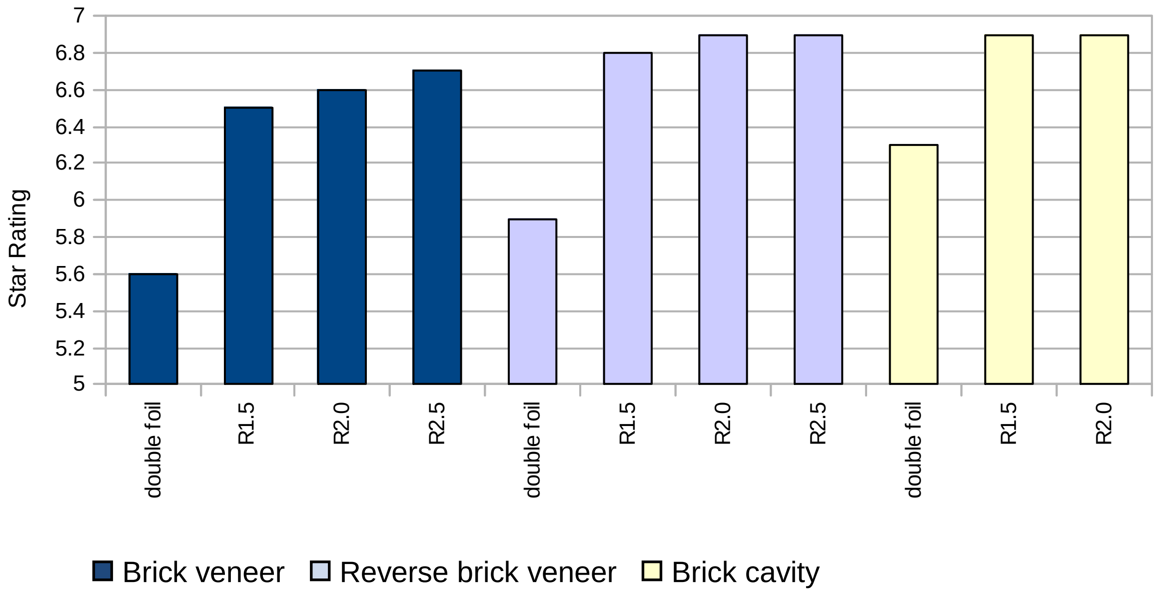

Figure 27: Comparison of the effect of wall construction and insulation on star rating for a single storey detached house (Dwelling 4) in Melbourne.

High Volume Residential Builder Survey – Summary of Responses

To better understand energy efficiency and cost issues faced by residential builders, a survey was conducted with participants from construction companies who provided plans for the study. While responses were not obtained from all of these companies, in total 28 individuals participated in the study.

As there were a small number of survey respondents in the study, it does not constitute a statistically valid sample of residential builders. However responses were obtained from some of the largest residential construction companies in Australia who represent a significant proportion of construction, so they do provide valid insights into experiences and concerns of residential builders.

The survey found that of the residential builders in states that had moved to 6 stars, they estimated an average construction cost increase of $3.5K. The largest estimated average cost increase was $8.5k. Interestingly one builder reported that they had not experienced any construction cost increase associated with meeting higher energy efficiency regulations provided that good orientation was possible.

In terms of whether these increased construction costs were passed on to home buyers, more than 80% of respondents passed 100% of construction cost increases on and 10% passed on 75% of the cost increase.

When survey respondents were queried about whether they had been able to reduce construction costs over time since implementation of higher energy efficiency regulations, there was a roughly 50% split for builders that had or had not been able to reduce costs. Builders that had reduced construction costs attributed this to a number of factors which included reduced material costs for products as they became standard, increased understanding of energy efficiency regulations, software and costs, and improvements to construction techniques, designs and business practices.

About one quarter of builders that participated in the study reported that energy efficiency was considered at the design stage while the other three quarters of respondents considered energy efficiency at a later stage of the process. Residential builders commented that designs are most commonly changed as needed to suit energy efficiency once selected for a specific location and block. However the vast majority of builders also reported that dwellings are designed to suit general climate types, then later tweaked to suit orientation and specific climates.

Almost all survey respondents reported that they have conflicting priorities between meeting energy efficiency requirements and other factors. In identifying conflicting priorities, two thirds of builders cited costs and home buyer budgets and one quarter listed other needs of home buyers such as lighting, and window size and orientation for views. A number of respondents also thought that increased home buyer education could alleviate some of these conflicting priorities. Other conflicting priorities identified by builders included local council requirements, air-tightness to improve energy efficiency causing condensation issues, difficulties of achieving 6 stars for houses that are built on slopes with raised sub-floors, and that energy efficiency and block orientation is often not considered when subdividing land.

Builders were also questioned about whether they have standard designs that voluntarily met higher star rating than required by regulations and, regardless of whether or not they did, if they thought there was interest from home buyers in this. The overwhelming majority of builders did not have designs that met a higher rating than 6 stars as they found that home buyers were primarily interested in cost not energy efficiency. Interestingly, the majority of builders thought that energy efficiency was fairly important to home buyers (Figure 28b), but cited cost as a barrier to achieving higher levels of energy efficiency.

In terms of whether energy efficiency regulation at different levels of government is clearly understood, most builders reported that they did not think it is, particularly by the general public but noted that there had been some improvement in general understanding overall. While they thought that the star rating system provided a good starting point for understanding energy efficiency regulation, where the more stars the better, builders recognised that it is difficult to explain energy efficiency regulations to home buyers. In terms of their own understanding of energy efficiency regulations, builders cited inconsistencies in energy rating software as well as inconsistencies between local council and federal regulations caused by poor understanding at the local council level as areas which created confusion.

The survey also included a broad question for builders to provide the opportunity to identify benefits or hindrances associated with meeting energy efficiency regulations. Most builders reported that they had experienced problems in meeting energy efficiency regulations, while few identified any benefits to their companies. As cost to home buyers is such an important priority, builders found it difficult to balance costs with more stringent regulations. They also found it difficult to meet energy efficiency regulations when faced with poorly designed and difficult block orientations, which they thought was often due to poorly designed subdivisions. Most builders thought that energy efficiency regulations have been fairly effective at meeting their objectives (Figure 28a).

Other issues cited by residential builders were the increased time to meet regulations, unclear regulations and that increased energy efficiency regulations have caused compliance problems for project home builders specifically who have difficulties for mass produced designs as opposed to custom designs. Builders also took the opportunity to raise concerns over future increases to regulations.

Other general comments made by builders included their concerns that there are inconsistencies between assessment from different assessors and that there is no government body to regulate assessors, which results in them selecting cheaper construction outcomes even though these may not be compliant with energy efficiency regulations. Several respondents highlighted the importance of auditing to ensure compliance with energy efficiency regulations.

When it comes to meeting energy efficiency regulations, a number of builders recognised that ultimately it comes down to what the home buyers want, which highlights the importance of education of the general public. Several builders thought that embodied energy should be factored into energy efficiency regulation and assessment to allow them to aim for carbon neutral rather than an “unaffordable” nine or 10 star homes.

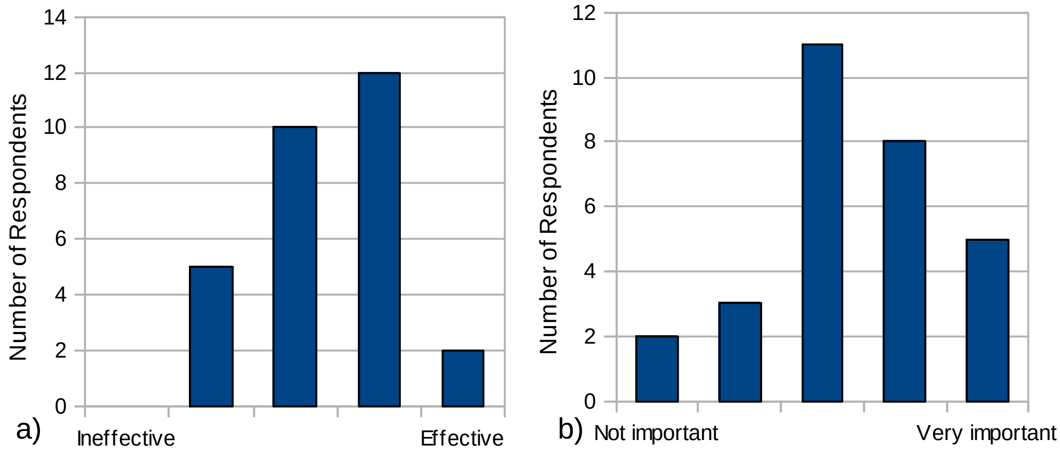

Figure 28: Number of respondents from builder survey for: a) how effective builders think regulations have been in improving energy efficiency of residential buildings in Australia, and; b) builders' experience of whether energy efficiency is an important consideration for home buyers.

Feedback from High Volume Residential Builders about Study Findings

Following the completion of this study several of the residential construction companies that provided plans for this study were contacted to obtain feedback about study findings regarding plans they had supplied. The builders were asked what they thought about how their dwellings had been redesigned and similarities or differences between cost estimates and their actual costs for the original and redesigned dwellings. This exercise highlighted several issues surrounding the redesign and cost estimates.

When queried about how cost estimates for the original designs compared to their costs (to home buyer) the vast majority of builders indicated that the prices provided by the quantity surveyor for this study were significantly higher. In fact many builders indicated that the costs were 30% higher or more, particularly cost estimates for larger houses. Only one of the builders indicated that a cost estimate was comparable to their cost which was for a small single storey house.

Interestingly some builders were not surprised that the cost estimates were significantly higher than their actual costs. Reasons they provided to explain this included that quantity surveyors tend to over-estimate costs and that costs for project home builders are well below average residential construction prices as a result of bulk purchasing of materials and other factors. As stated in the methods, to overcome cost discrepancies we also presented percentage cost change between the original and redesigned dwellings in addition to dollar figures.

Several builders also raised concerns about cost variation associated with redesign changes. These were due to either locally specific issues or commercial concerns which were seen as more important than construction costs. Examples of locally specific issues which were raised by Perth builders were: 1) construction of reverse brick veneer in Perth is more expensive to build with than double brick due to the need to take extra measures to prevent termite infestation and that the industry is geared towards this construction method, and; 2) reduction of eaves widths would require reconfiguration of roof framing and potentially increase construction costs. A commercial concern of some builders related to window size reductions which, although builders agreed would achieve a cost saving, could make their products less attractive and decrease sales.

In general builders were very interested in the outcomes of the study particularly with regards to the effect it might have on future energy efficiency legislation. Most builders also indicated that they were willing to supply actual costs to improve the accuracy of the study. It is suggested that further time spent analysing average builders' costs would improve the outcomes of this study. However in reality it is unavoidable that cost changes will not suit all builders as construction costs vary between companies, but the study provides a good indication of cost effective redesign options and percentage cost savings achievable across Australia.

Discussion

Energy Efficiency and Dwelling Costs

Perceived building cost increases to meet minimum energy efficiency targets have hindered increasing the stringency of energy efficiency regulations for new homes in Australia. This study shows that in general it is possible for high volume residential dwellings to cost effectively achieve 6 stars by applying good design principles.

Currently many volume residential builders use the same plan across a wide range of climates and for all orientations. Although home builders often alter some design features and specifications to suit different climates, designs are not typically optimised to suit different orientations. Rather volume homes, particularly detached houses, tend to be designed for every orientation with windows distributed evenly around the home. This approach gives a similar level of performance in each orientation, slightly higher where the building enjoys the best orientation and slightly lower in the worst orientation. Consequently the majority of new homes built in Australia are designed to achieve an average result rather than optimal energy efficiency performance.

In redesigning dwellings to affordably meet 6 stars, this study applied many well-known design principles (Your Home Technical Manual), such as glazing orientation and eave widths. It also demonstrated that there are a number of effective no-net cost changes, including roof colour optimisation in all capital cities and polystyrene core concrete slab on ground in cold climates. By applying good design principles the study redesigned all high volume homes with CSOG to exceed 6 stars with standard glazing in all capital cities.

Designing for Energy Efficiency by Climate Type and Orientation

When designing a dwelling to suit different climate types and orientations, window specification and size should relate to the movement of the sun through the sky and annually through the year. In the majority of occupied Australian climate zones heating and cooling loads are both significant and there is also a large movement of the sun up and down the sky during the year. The heating load can be ameliorated by allowing passive heating in winter, and the cooling load diminished by restricting direct solar access onto the glass during the summer months.

In temperate and colder climates the study demonstrated that energy performance could be improved in this way by moving glazing to the northern face of a dwelling. In the temperate climates shading was also optimised by designing eaves of an appropriate width which provided shading in the summer months, but which also allowed passive heating in winter. The study also showed that in cold climate cities dwellings generally performed best in the absence of any form of shading from eaves or verandahs.

In the hotter climates where there is no appreciable heating load the redesign process was more to do with shielding the living areas from the heat. Moving the living areas to the northern or southern face of a dwelling in combination with shading proved effective.

It is important to get orientation right. While it is possible to design dwellings that perform adequately across multiple orientations, for the best energy efficiency performance outcomes dwellings can be optimised to specific orientations. Matching dwellings with appropriate orientations can significantly reduce construction costs and resources wasted on unnecessary higher performing construction materials.

Cost Effective Redesign in Hot Climates

For the purpose of this study, the only capital city that was considered a hot climate was Darwin. The study found that a number of design changes to be very effective in this climate types, which included:

- Avoiding living areas orientated on the eastern or western facades;
- Minimising east and west facing windows, by either reducing window area or relocating windows to northern and southern facades;
- Increasing ventilation, by adding ceiling fans (particularly to daytime occupied zones) or ventilation (such as whirlybirds) to the roof space. Increasing openable area or windows would have also been an effective design change but it was found that this would increase construction costs so this option was avoided;
- Increasing hard floor surfaces and minimising carpeted areas, particularly effective for daytime occupied zones. In this case vinyl flooring was used to replace carpet, although it would have been similarly effective if polished concrete, floating timber floor or tiles;
- Addition of internal doors to zone off unconditioned areas, such as corridors from conditioned spaces.
- Reflective foil to roof;
- Light roof colour, with a solar absorptance of 30%;
- Wide eaves to maximise shading.

Cost Effective Redesign in Temperate Climates

While redesign of dwellings was generally undertaken by climate type, some designs changes that were typically only used for Darwin would have also proven effective for the temperate climates. This is particularly true for Brisbane which has a very high cooling load (although it does have a heating load), and consequently the addition of ceiling fans or increasing ventilation could have improved the star rating, although these design changes were infrequently used for the temperate climates. Design changes that were most typically used for the temperate climates incorporated some changes typical to both hot and cold climates:

- Hard floor surfaces in the living zones;
- Generally a light roof colour improved the thermal performance in temperate climates, provided that there was no roof insulation. However occasionally designs performed best with an intermediate roof colour in the cooler temperate climates, such as Adelaide.
- Minimising east and west facing windows and ensuring adequate north-facing window area to facilitate passive heating in winter and minimise solar heat gains in winter;
- Reflective foil to roof;

- Addition of internal doors to zone off unconditioned areas, such as corridors, from conditioned spaces.

Cost Effective Redesign in Cold Climates

The capital cities that were considered cold climates for the purpose of this study, Canberra, Melbourne and Hobart, generally responded well to the following design changes:

- Polystyrene core to concrete slab on ground floor;
- Ensuring adequate window area to the northern facades;
- Replacing permanent roof covering to outdoor areas with removable shading (such as shade sails) to allow passive solar heat gains in winter and exclude solar heat in summer;
- Reducing or eliminating other permanent external shading including eaves;
- Carpet floor covering;
- Addition of internal doors to zone off unconditioned areas, such as corridors, from conditioned spaces.

Glazing Area

Glazing area can be one of the most important factors that contribute to a building's thermal performance. The insulation value of the windows is comparatively much less than the walls or ceiling minimum insulation levels.

Large areas of glazing help to sell buildings as they are valued by the home buyer. It is possible to use the ratio of window to floor area as a metric in assessing the level of glazing in buildings, in consideration with glazing orientation and other factors. Typically volume homes similar to those in this study have a window to floor area ratio around 20 to 25%. Bespoke designs can have as much as 45% window to floor area ratio.

Multiple paned glazing units can make an enormous difference to the thermal performance of a building. While there is general acceptance that improved glazing will become the norm, there is currently an appreciable cost to improving the glazing.

In working with builders to achieve the minimum thermal performance as energy efficiency assessors we find that it is often necessary to specify improved glazing due to impediments in the optimal siting of a building. Where block layout is good and the design can take advantage of the site it is possible to meet the minimum thermal performance with single glazed buildings with standard frames as demonstrated in this study.

Air-Conditioning

The take-up of mechanical heating and cooling (air-conditioning) has increased markedly over the past 10 years (ABS website), with a large percentage of residential construction being air-conditioned as a matter of course. Air-conditioning has become pervasive not only in residential buildings but in the workplace and in transport. A majority of people expect to be able to control the temperature of their environment at all times. This expectation is reflected in the NatHERS software assuming that all buildings will be heated and cooled for temperature regulation.

The ability to control temperature of the internal environment has led to a change in the way houses are designed. To an extent they are now designed to be isolated from the climate they are in and allow for internal temperature control. To design a building which has a different internal temperature than the external temperature leads to efforts to stop the movement of heat through the building fabric.

While this leads to insulated buildings, using the positive aspect of the building's location, such as free winter heating from the sun, can be beneficial to the amount of energy needed for heating and cooling.

Home Buyers' Choice

Home construction is complex and the number of decisions of the new home buyer can be overwhelming. As demonstrated in this study, there are a wide range of variables which impact on a building's thermal performance such as building design, window size and aspect, external cladding colours, floor coverings, and positioning and size of shading. The choice and the effect are dependent on climate and orientation.

Where the client's choice aligns with the best choice for thermal performance, meeting the minimum performance standard is possible with no or minimal cost increase. Where the home buyer moves away from the beneficial thermal performance choices it is still possible for the requirements to be met though there may be a cost increase.

Builder survey results highlighted the lack of knowledge among both the home buying public and the sales staff about the impact of choice on the thermal performance of the building. Ideally volume home builders would provide a series of choices of suitable designs for a specific site location and orientation.

Limitations to this Research

Costs

The primary aim of this study was to identify cost effective redesign options. It did not consider the most energy efficient changes independent of cost. However construction costs may vary considerably between construction companies so individual companies might find that greater cost savings can be achieved using different design changes than those presented here. Furthermore, construction costs vary over time, so different energy efficiency improvements than those considered as part of this study may become cost effective into the future.

While the study found that construction costs could be reduced, in reality this may actually be associated with some cost increases elsewhere. This may include additional effort by construction companies to better understand how their designs perform in different climate types and orientations, in optimising designs for specific conditions, and educating sales staff to enable them to recommend suitable designs to home buyers. However, these added costs may be able to be spread over a number of dwellings constructed to the new design. Any additional costs associated with these activities have not been quantified by the study, nor have any potential financial benefits to construction companies associated with providing a more competitive product in the market.

User Behaviour

NatHERS software assesses the potential for a building to be used in an energy efficient manner. For example, the software assumes that internal doors will be closed by occupants to reduce the total area required to condition a living zone. In reality it is possible for the dwellings examined in this study, specified to meet the energy efficiency standard, to be operated in a way that uses more energy than predicted by the software.

Study Timeframe

The study budget influenced many of decisions regarding study design and scope. For example this limited the potential to redesign dwellings optimally for each capital city or by dwelling type, particularly for manual redesign changes. Limited study duration also reduced the potential to undertake a pilot study to identify the best redesign changes for different dwelling types and locations. It also meant that in some cases the best design principles were not applied to the redesign of dwellings, although overall energy efficiency was improved with a cost saving. Given more time the study would have achieved better outcomes which would have undoubtedly resulted in increased construction cost savings.

Recommendations

House Design

Rather than considering energy efficiency once a house design has been selected, higher energy efficiency performance and reduced construction costs could be achieved if energy efficiency was considered at the design stage. Similarly, if volume home builders were more aware of how dwelling designs perform in different orientations and climatic conditions, they could recommend suitable designs to home buyers, and steer them away from unsuitable designs. While it may be possible to increase dwelling energy efficiency with higher performing specifications as is the current approach to meeting energy efficiency, this can result in increased construction costs and unnecessary wastage of materials.

Project home builders prefer to have designs that could be used in any orientation but the study highlights the potential cost savings if dwellings are optimised for different orientations and good design principles are applied. At a minimum, builders could develop two variants of their designs (i.e. for north-south and east-west orientations) and still achieve good cost savings similar to those presented in the study.

Regulation

Although energy efficiency standards are now well-established within the construction industry, there is currently very limited or no auditing to ensure that houses are constructed to meet these standards. It seems a logical progression of the regulations for auditing to become commonplace both in terms of energy efficiency assessments as well as of houses during construction. The survey of residential builders found that there is some support for this within the industry.

As identified by residential builders, one of the impediments that they face in meeting energy efficiency standards come from having to work around poorly designed block orientations. Consequently more consideration of energy efficiency needs to be undertaken at the land sub-division stage. Potentially there could be some form of regulation introduced at this stage of development.

Education

Residential builders involved in this study raised concerns regarding difficulties faced when dealing with home buyers who they thought generally have a poor understanding of energy efficiency regulations. One solution to this issue might be an education program, possibly provided by the federal government, regarding methods for project home builders and their sales staff to pass on information about energy efficiency to home buyers. To some extent this could also alleviate some of the issues of conflicting priorities between energy efficiency and other needs of home buyers.

Concerns were also raised by residential builders that there may be some conflicts between local council and federal energy efficiency regulations. Although this is anecdotal evidence, there may also be some benefit from energy efficiency regulation education programs aimed at the local council level.

It is possible for home owners to operate the homes inefficiently. The NatHERS software only predicts potential energy efficiency levels. Actual energy efficiency of dwellings could be further improved by educating home owners about how to operate their home efficiently. Education programs about ways for home owners to reduce their energy bills are already available to the general public and have been for a number of years, but this is an optional service. Perhaps energy efficiency within the residential sector could be further improved if new home owners were given a manual about how to operate their homes in an energy efficient manner, in the same way as commercial buildings are given a user manual when rated via the Greenstar program.

Future Studies

Increased Costs from Optimising Plans

This research highlighted that it is possible to reduce construction costs provided that designs are better optimised to suit specific climates and orientations. There may be some increased costs associated with redesigning plans, educating sales staff, or adopting new construction methods. It would provide a useful insight and comparison to understand how these possible increased costs influence potential construction cost savings presented in this study.

How Do Construction Costs Change Over Time?

There is an idea that the initial change to meet higher energy efficiency regulation incurs an ongoing cost. However, this cost may reduce over time as changes are incorporated into design and construction practices, and as new products come into the market. How could these effects of industry learning and adoption of standard construction materials be quantified in relation to construction cost changes over time?

Highest Star Rating with No Cost Change

This study found that dwellings could generally be redesigned to meet higher energy efficiency regulations with reduced construction costs compared to a 5 star dwelling. It would be interesting to take this one step further to identify the maximum achievable star rating with no increase to construction costs.

Sub-Division Design

To explore the validity of concerns raised by residential builders in this study, it would be useful to investigate how subdivisions are currently designed and what effects this has on energy efficiency of dwellings.

Conclusions

This research investigated the potential cost increases associated with meeting 6 star energy efficiency regulations or, for the case of Adelaide and Canberra, whether there was scope to reduce construction costs to meet the same energy efficiency levels. The study outlines a range of design changes that can be effectively used to improve energy efficiency in the eight capital cities in Australia, which represent the range of climate types in Australia. Research findings demonstrated that it is possible to improve dwelling energy efficiency levels by one star to meet higher energy efficiency provisions with reduced construction costs rather than increased construction costs as widely reported in the construction industry.

As identified by residential builders' themselves, project homes in particular can face difficulties in meeting higher energy efficiency regulations because they are designed to suit a range of climates and orientations. By investing some effort in tailoring designs to suit different orientations and climatic conditions, construction costs could be reduced to allow residential builders to offer a more affordable product in a market where cost is the bottom line.

References

ABS (Australian Bureau of Statistics) website: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4602.0.55.001/

NatHERS website: http://www.nathers.gov.au/

Rawlinsons (2011). *Construction Cost Guide 2011 for Housing, Small Commercial and Industrial Buildings, Edition 19.* Rawlinsons Publishing, Perth, Western Australia.

Waffle Pod website: http://www.wafflepod.com

Your Home Technical Manual website: http://www.yourhome.gov.au/technical/index.html

Appendix 1: Average Star Rating Change and Cost Saving (%) for Dwellings 1-20 by Capital City.

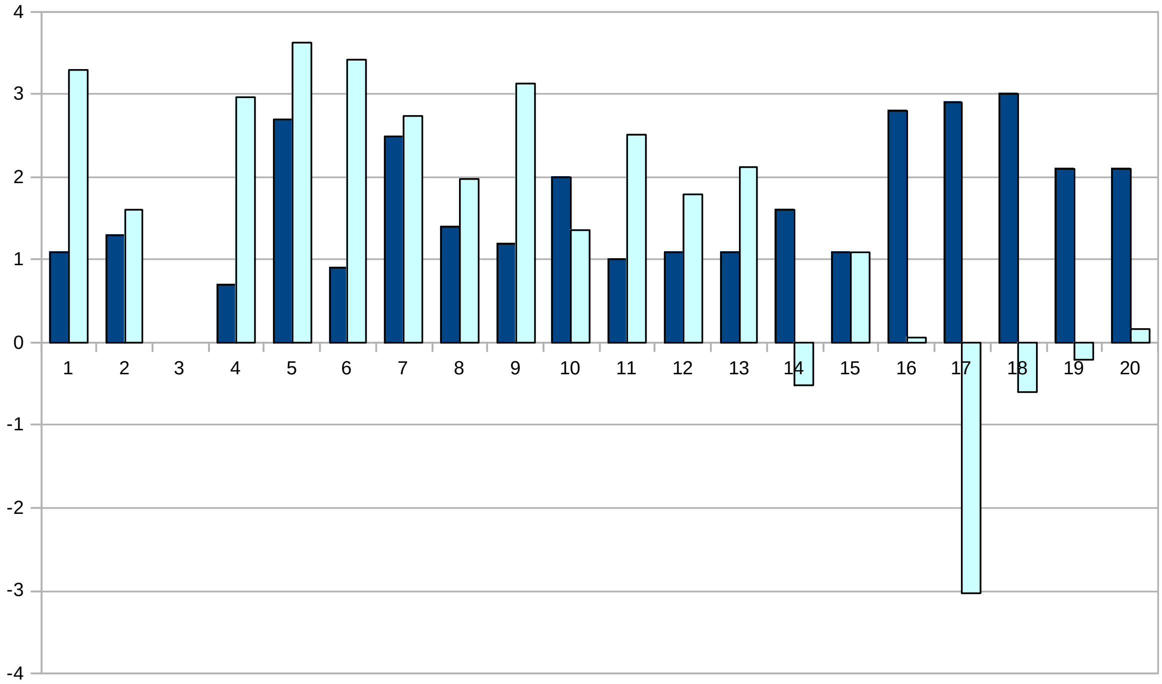

Figure 29: Star rating change and cost saving (%) in Darwin for each dwelling as a result of redesign changes.

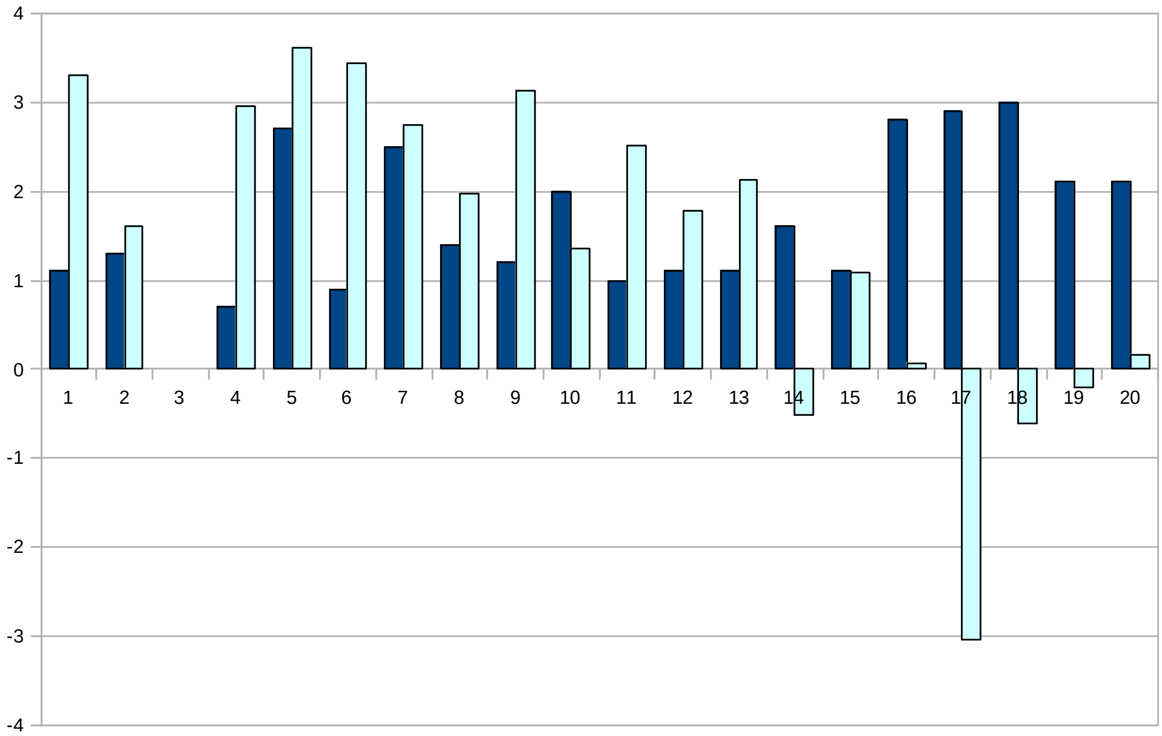

Figure 30: Star rating change and cost saving (%) in Brisbane for each dwelling as a result of redesign changes.

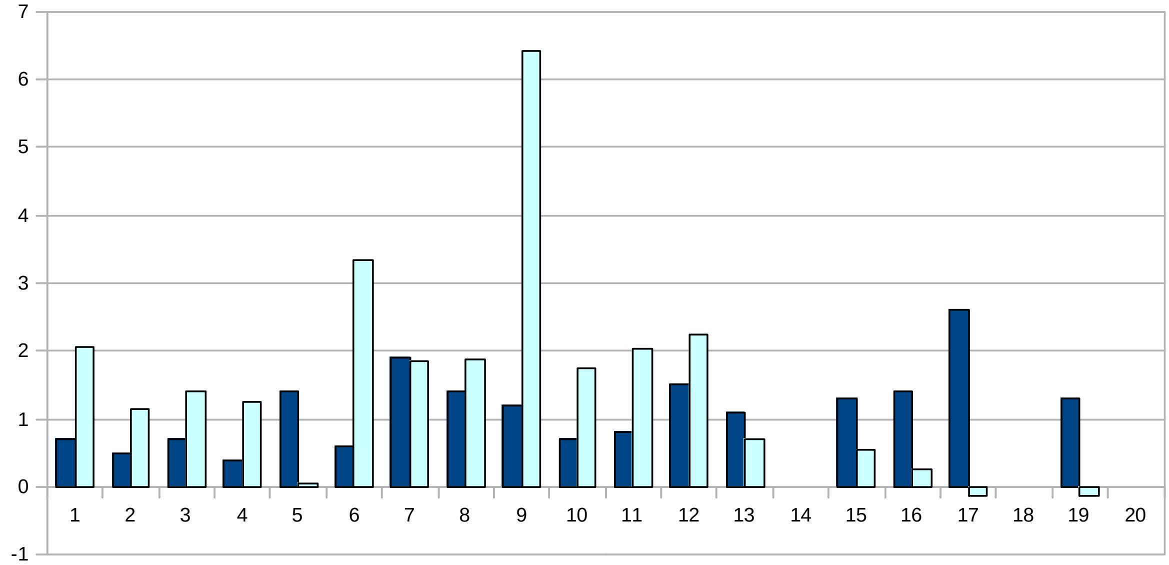

Figure 31: Star rating change and cost saving (%) in Perth for each dwelling as a result of redesign changes.

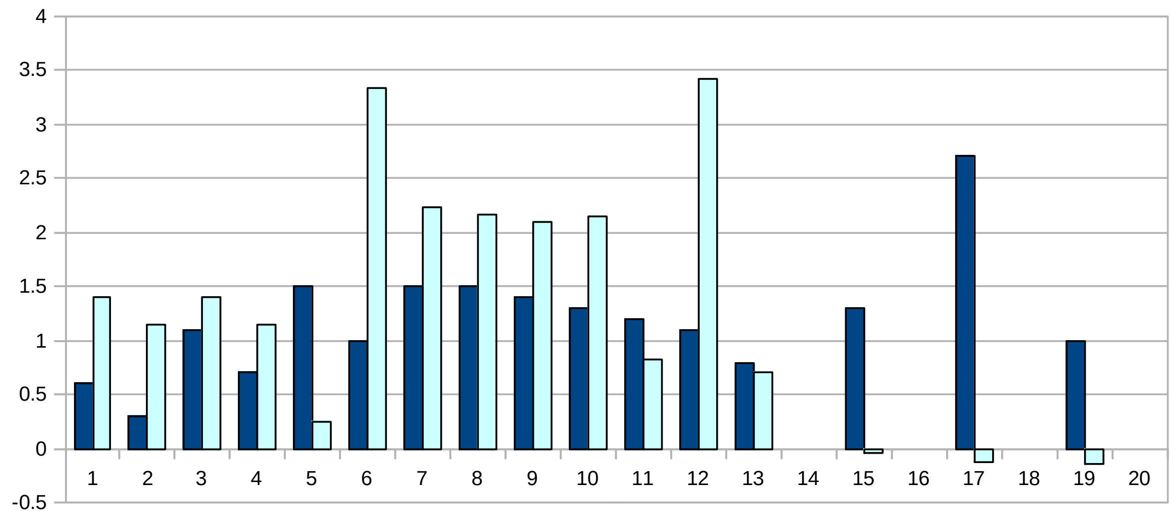

Figure 32: Star rating change and cost saving (%) in Sydney for each dwelling as a result of redesign changes.

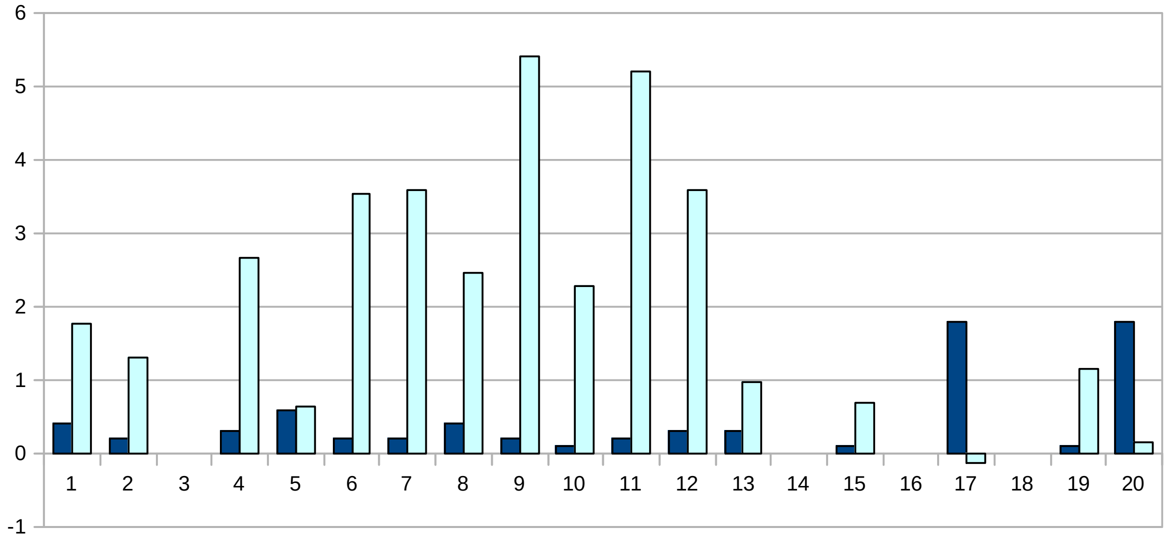

Figure 33: Star rating change and cost saving (%) in Adelaide for each dwelling as a result of redesign changes.

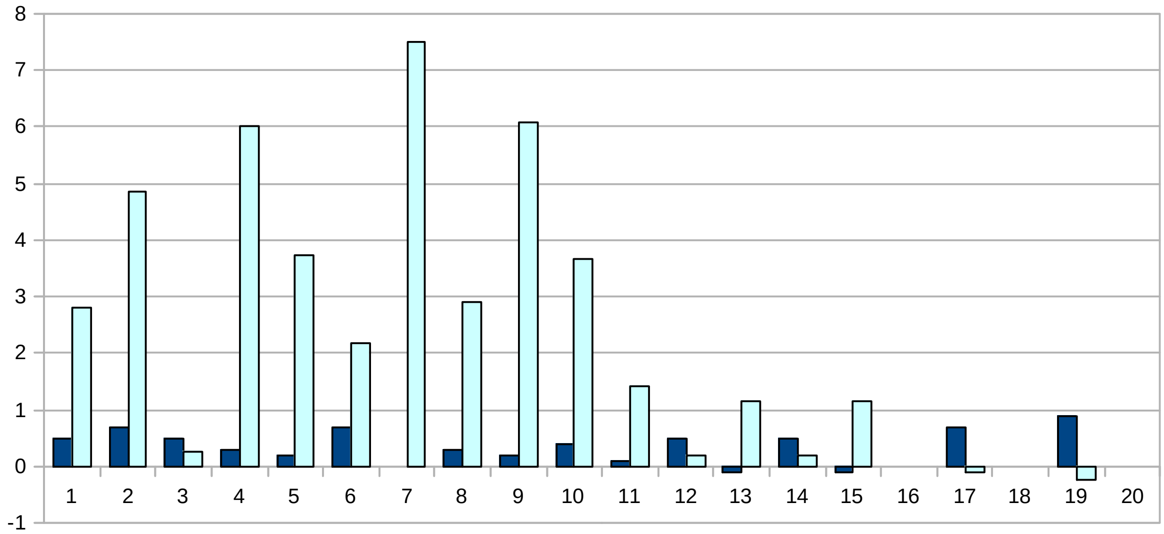

Figure 34: Star rating change and cost saving (%) in Canberra for each dwelling as a result of redesign changes.

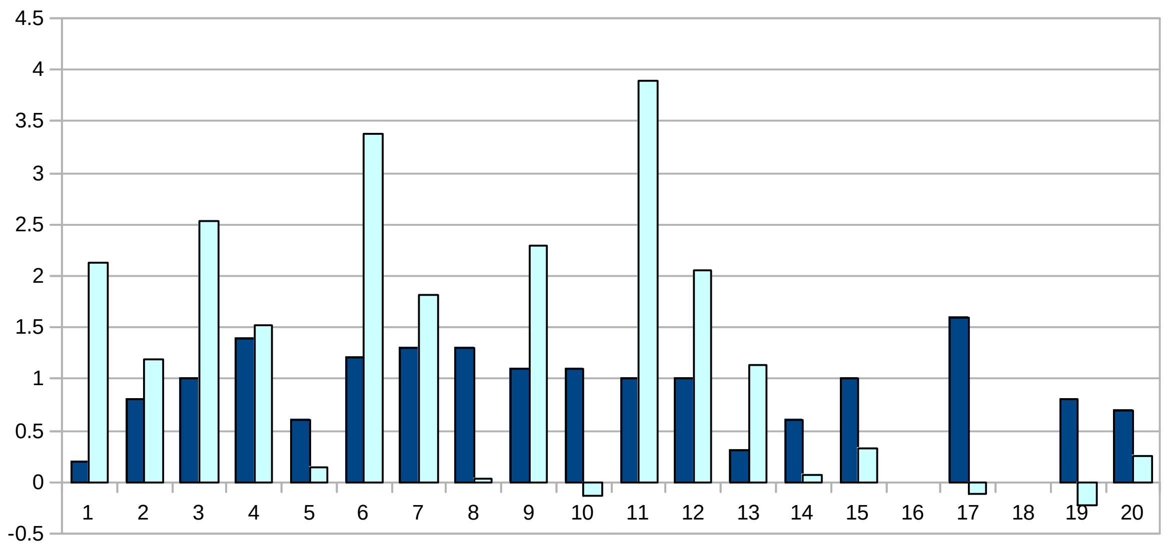

Figure 35: Star rating change and cost saving (%) in Melbourne for each dwelling as a result of redesign changes.

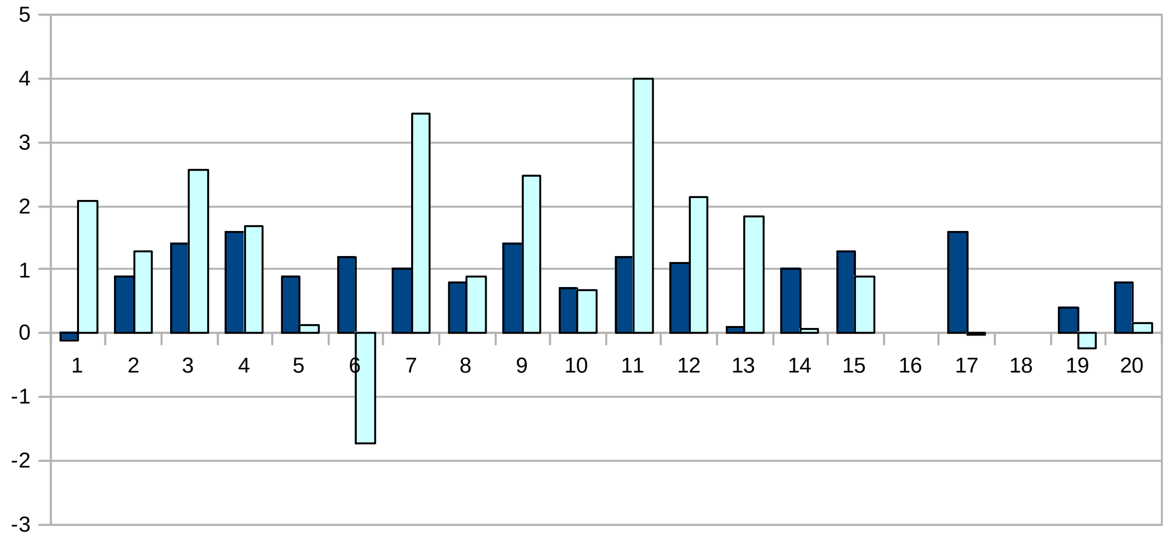

Figure 36: Star rating change and cost saving (%) in Hobart for each dwelling as a result of redesign changes.

Appendix 2: High Volume Residential Builder Survey Questions

1. What energy efficiency compliance methods do you typically use for residential buildings?
2. How does your company complete energy efficiency assessments?
3. Did you experience construction cost increases as a result the latest increased energy efficiency provisions (e.g. move to 6 stars), and if so can you estimate the average cost increase per house?
4. What percentage of extra costs is passed on to customers?
5. Have you been able to reduce construction costs over time, and if so, in what ways have you reduced these costs?
6. Do you develop your standard designs to achieve a particular star rating, or is this considered after the design is settled?
7. Do you develop house designs that can be built in any city, or do you tailor your designs to particular locations and climates?
8. How effective do you think that regulations have been in improving energy efficiency of residential buildings in Australia?
9. Do you find that you have conflicting priorities between meeting energy efficiency requirements and other factors, and if so what are these?
10. Based on your experience, do you think that building energy efficiency is an important consideration for home buyers?
11. Do you have any standard designs that voluntarily achieve higher star rating requirements, such as 7 or 8 stars? If so, do you get much interest from home buyers for these plans?
12. Do you provide air conditioning as a standard inclusion in your house? What is the demand for air conditioning from home buyers?
13. Do you feel that energy efficiency regulations are clearly understood (national and state/ local planning requirements)?
14. Can you identify any benefits or problems to your company in meeting energy efficiency regulations?
15. Any other comments?