The Cost Effectiveness of Housing Thermal Performance Improvements in Avoiding CO_2- emissions

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Declaration of Originality

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June 2013

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Published Papers

The following two papers were written as result of research undertaken for this thesis.

McLeod, P. and R. Fay (2011) "The cost effectiveness of housing thermal performance improvements in saving CO_2-e" Architectural Science Review Volume 54, Issue 2: 117-123

McLeod, P. and R. Fay (2010) "Costs of improving the thermal performance of houses in a cool-temperate climate" Architectural Science Review Volume 53, Issue 3: 307-314

ABSTRACT

It is widely recognised that the built environment is a significant contributor to greenhouse gas emissions worldwide. In Australia, to reduce the greenhouse gas emissions associated with new houses, energy efficiency provisions were introduced into the Building Code of Australia (BCA). The primary focus of the regulations has been on achieving thermal comfort through a reduction in the energy houses require for heating and cooling (space-conditioning energy). A star rating system is used to indicate the level of thermal performance a new house achieves. Ratings range from 0 to 10 stars and theoretically, the higher the star rating the less space-conditioning energy a house requires. Currently, all new houses built in Australia require a minimum of either a 5 or 6 star rating, depending on the state/territory, with the required minimum level expected to increase incrementally in the future.

It is widely claimed that there are considerable opportunities for cost effective greenhouse gas abatement in the residential building sector. However, the claims generally neglect to take into account any increase in embodied energy (and associated emissions) that may result from implementing those opportunities. Increasing a house's thermal performance generally increases its embodied emissions. Current research findings indicate that embodied energy and its associated emissions can contribute significantly to a house's life-cycle energy and CO_2-emissions, with that contribution increasing the more thermally efficient a house becomes.

The aim of this research was to determine and rank the cost effectiveness of a wide range of thermal performance improvements, for houses with ratings from 4 to 8 stars, taking into account their embodied emissions. To achieve this, several project homes constructed in Tasmania whose size and floor plan varied were selected. Using thermal simulation software the space-conditioning energy requirements of the thermal performance improvements were calculated. The cost of each thermal performance improvement was estimated and the resulting increase in embodied energy calculated. For each house, timber floor and slab-on-ground designs were modelled.

The same thermal performance improvements were made to each house. These were ranked for their cost effectiveness in reducing space-conditioning emissions, minimising the increase in embodied emissions and reducing net emissions. For each measure of cost effectiveness, the rankings were compared to determine the effect house design and house size had on the results.

The results show that the cost effectiveness of achieving pre-determined levels of thermal performance varies significantly depending on the methods and materials used. There are numerous methods that can be used to improve the thermal performance of a house to a certain level, with costs varying significantly. While generally the most and least cost effective designs in minimizing embodied emissions are the same for each house, some design differences between the houses are a significant factor in determining how cost effective improvements will be in minimizing embodied emissions. In terms of cost effectiveness in reducing net emissions the results show that for lower star band ranges (5-6 star), the most cost effective designs in reducing net emissions are also the most cost effective in saving space-conditioning emissions. However, in the higher star band ranges cost effectiveness in saving space-conditioning emissions cannot be used to predict reliably the cost effectiveness in saving net emissions. Finally, the results shows that while heating appliance type and efficiency do not affect cost effectiveness rankings, the choice of heating appliance is significant in determining whether an increase in embodied emissions outweighs a decrease in space-conditioning emissions and at what level of thermal performance that occurs.

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CHAPTER 1 – INTRODUCTION

1.1 BACKGROUND

The building sector is a large consumer of energy and a significant contributor to greenhouse gas emissions worldwide. It contributes up to 30% of global annual green house gas emissions and consumes up to 40% of all energy. Given the massive growth in new construction in emerging economies, together with energy inefficient existing building stock worldwide, in the absence of action, greenhouse gas emissions from buildings will more than double in the next 20 years (UNEP 2009). In Australia, the buildings sector accounts for 130 Million tonnes (Mt) of greenhouse gas emissions each year, which is around 23 per cent of Australia's emissions. Buildings sector greenhouse gas emissions are projected to grow to 280 Mt by 2050, an increase of 110% (ASBEC 2010).

For the average Australian home, energy used for heating and/ or cooling (space conditioning) accounts for 39% of its total energy use and about 20% of its total greenhouse gas emissions (DEH, 2008). Nonetheless, it is claimed that the building sector has the potential to cost effectively reduce greenhouse gas emissions worldwide (Menon and Porteous 2008).

A review of studies of the greenhouse gas abatement opportunities in the residential sector estimated that by 2020 approximately 29% of the projected baseline emissions of the world's buildings can be avoided cost effectively, with 3% of baseline emissions being avoided for less than US$20/tonne CO_2 (Urge-Vorsatz and Novika 2008). With regard to the Australian building sector, the consultants McKinsey and Company (2008) found that by 2030, a total of 60Mt of carbon reduction opportunities can be found, all at low or negative cost. Mirasgedis et al. (2004) note that in terms of CO_2-e mitigation policy, the monetization of environmental benefits is a powerful tool in highlighting priority actions. Quantifying the greenhouse gas emissions that can be saved through various housing energy efficiency measures, and their costs, provides a way to optimize costs and greenhouse gas emissions reductions.

In Australia, the primary focus of regulations aimed at greenhouse abatement in the residential building sector has been on reducing the energy houses require for heating and cooling (space-conditioning). A star rating system is used to indicate the level of thermal performance a new house achieves. Ratings range from 0 to 10 stars. Theoretically, the higher the star rating the less space-conditioning energy a house requires. Currently, all states and territories in Australia require a minimum 5 or 6 star performance. This is likely to be increased incrementally over the next decade.

Claims that measures taken to achieve thermally efficient houses will be cost effective from a societal perspective (that is, the benefits of avoided CO_2 emissions outweigh the costs of abatement), overlook the embodied emissions associated with the measures. For some energy efficiency measures, there may be no or very little increase in embodied emissions, for example, changing to more efficient lighting or more efficient household appliances. However, the embodied emissions associated with thermal performance improvements, such as installing double-glazed rather than single-glazed windows, adding thermal mass and/or high levels of bulk insulation, may be significant. The embodied emissions of these improvements could significantly offset the reductions in space-conditioning emissions, thus reducing their cost effectiveness. The extent to which this is the case would depend on the level of thermal performance being sought.

It is now widely accepted that embodied energy can make a significant contribution to the life cycle energy and consequently the life cycle CO_2 emissions of a house. As a house becomes more energy efficient the greater the contribution embodied energy makes to life cycle energy. Improving the thermal performance of a house not only increases the ratio of embodied energy to space-conditioning energy, but it may also increase its total embodied energy.

1.2 THE PROBLEM

To reduce the CO_2 emissions associated with the energy needed to heat and/or cool houses, the Building Code of Australia (BCA) requires that new houses meet a minimum level of thermal performance. The introduction of thermal performance standards, and each subsequent increase, has been subject to a regulatory impact assessment. As part of that process the costs of meeting the proposed standard (star rating) are investigated and estimates of the greenhouse gas emissions that can be achieved as a result are calculated. However, the process overlooks the associated embodied emissions and their effect on the cost effectiveness of higher thermal performance standards.

The goal of the BCA's energy efficiency provisions is to 'reduce greenhouse gas emissions by using energy efficiently" (Building Code of Australia 2009). The BCA regulations apply to all new houses irrespective of the greenhouse gas emissions factor associated with a house's space-conditioning energy (even if it is 100% renewable and zero emissions); the presumption is that measures taken to reduce space-conditioning energy will reduce greenhouse gas emissions. If the increase in embodied energy in order to comply with regulations is significant, the goal of the BCA could become compromised, particularly if the energy associated with materials to improve thermal performance has a higher greenhouse gas emissions factor than the space-conditioning energy that is to be saved as a result. In turn, this will affect the cost effectiveness of thermal performance measures.

As it stands there are several factors that remain unclear about incrementally increasing thermal performance regulations for typical Australian housing. They are the capital cost and design implications and, therefore, the cost effectiveness of thermal performance improvements in avoiding CO_2 emissions. This represents a gap in the existing knowledge about the potential impact of higher thermal performance standards on Australian housing.

1.3 RESEARCH AIM

The aim of this research is to determine and rank the cost effectiveness of a wide range of methods and materials that could be used to achieve incrementally higher levels of thermal performance.

In addressing the research aim there are number of questions that will be addressed.

- While one thermal performance measure may be more cost effective than others in saving space-conditioning emissions, do rankings of measures change when embodied emissions are taken into account?
- Do the relationships between rankings in saving space-conditioning emissions with and without taking into account embodied emissions change as thermal performance increases and/or across different house designs?
- Is there a point reached where spending more than a certain amount on improving a house's thermal performance leads to an increase rather than a decrease in $C0_2$-emissions?

1.4 THESIS STRUCTURE

Chapter 2 outlines the history of house energy rating schemes in Australia and describes their effectiveness in reducing greenhouse gas emissions. Reasons for the resistance to both their introduction, and subsequent increases to the minimum level of thermal performance are described. Embodied energy, its contribution to life cycle energy, and its relationship to energy used for heating/cooling are also examined.

Chapter 3 discusses the design implications of higher thermal performance standards and factors that affect the capital costs of energy efficiency measures. Previous studies that examine payback periods and life cycle costs associated with housing thermal performance measures are reviewed.

Both Chapters 2 and 3 identify the shortcomings of previous research with regards to the assessment of thermal performance measures and their cost effectiveness in saving CO_2 emissions.

Chapter 4 describes the research method used to test the main hypothesis and to address the primary research aim and research questions. It outlines the scope of the study in terms of climate, typical housing typologies, and the likely levels of thermal performance that housing will be required to achieve, and a range of options to achieve them.

Chapter 5 presents the results and Chapter 6 discusses and analyses those results. Chapter 7 presents the conclusions of the research and makes recommendation for further research.

CHAPTER 2 – BACKGROUND

2.1 INTRODUCTION

This chapter gives a history of the development of house energy rating schemes in Australia and describes their effectiveness in reducing greenhouse gas emissions. Reasons for the resistance to both their introduction, and subsequent increases to the minimum level of thermal performance are outlined. One of those reasons, it has been argued, is that regulations are too narrowly focused on space heating and cooling energy, and that they should be broadened to include the embodied energy of building materials. Embodied energy, its contribution to life cycle energy, and its relationship to energy used for heating/cooling are described.

2.2 HOUSING ENERGY RATING SCHEMES AND REGULATIONS IN AUSTRALIA

2.2.1 Background

In the 1980s, the Five Star Design Rating (FSDR) scheme was developed and adopted in NSW, Victoria and South Australia. The FSDR certified houses that met a number of requirements for energy efficient design based mainly on glass area, thermal mass quantity and insulation levels (Ballinger 1998). However, it was not widely accepted by industry because of its restrictive design guidelines.

During the 1990s individual states began to develop their own House Energy Rating Schemes (HERS). The most effective was the Victorian scheme, which was based on a computer program. However, because it was not suited to all climates of Australia, a more flexible nationwide HERS (NatHERS), was developed that could be applied to the different climate zones of Australia (Kordjamshidi 2009). The aim was to create a rating for a house's energy efficiency. Using a computer program, a graded five-star rating system has been used to show the relative energy efficiency of houses. HERS predicts the demand for heating/cooling energy required to maintain thermal comfort. After 1998 it was implemented in NSW as the Energy Smart Rating Scheme and adopted by local councils voluntarily. Although the scheme was voluntary, by 2002 a majority of NSW local councils required compliance for building approval.

The first thermal performance regulations in Australia were in Victoria in 1991. The primary aim of the regulations was to improve the thermal comfort of houses rather than to increase energy efficiency. While Australian Standards recommending housing insulation levels for the various climate zones across Australia existed prior to this, they were not mandatory.

In 1996, the ACT government introduced a requirement that new houses have a minimum 4-star energy standard (Commonwealth Scientific and Industrial Research Organisation 1999).

In March 1999, the Federal Government and the Australian Building Energy Council (ABEC) agreed on a strategy to reduce the energy consumption of buildings by introducing mandatory minimum thermal performance standards in the Building Code of Australia (BCA) as well as encouraging voluntary best practice measures by industry (ABEC 2009). The mandatory BCA regulations were designed to eliminate worst practice whereas the voluntary guidelines were aimed at encouraging best practice.

In 2000, all states and territories of Australia agreed to adopt thermal performance regulations in the Building Code of Australia. The Australian Building Codes Board (ABCB) and the Australian Greenhouse Office (AGO) signed a Memorandum of Understanding to jointly develop the BCA Energy Efficiency Provisions in 2001 (ABCB 2010). In August 2002, the Australian Building Codes Board announced that national energy efficiency provisions would be introduced in the BCA (ABCB 2010). The provisions aimed to reduce residential energy consumption used in space heating and cooling and to increase thermal comfort by encouraging improved building design. The strategy defined an acceptable minimum level of energy efficiency for new buildings. Thermal performance regulations for domestic buildings were introduced into the BCA in July 2003 (ABCB 2010). New houses were required to a meet mandatory minimum thermal performance rating of 3.5-4 stars. Minimum thermal performance requirements are measured by star ratings, which reflect a house's predicted operational heating and cooling requirements. Star ratings range from 0-10 stars. The higher the star rating, theoretically the less space-conditioning energy a house requires to maintain predetermined comfort levels.

Since their introduction, individual states and territories have phased in increases of the minimum thermal performance requirement. In May 2005, Victoria adopted a minimum 5-star requirement followed by SA, the ACT, and WA in May 2006. NSW, Queensland, and Tasmania have since adopted the 5-star standard. In July 2004, the NSW state government introduced the Building Sustainability Index (BASIX), which replaced the BCA energy efficiency regulations in that state, to ensure homes are designed to use less water and are responsible for fewer greenhouse gas emissions than a standard home. With BASIX, energy efficiency requirements extend beyond minimising energy needed for space-conditioning to include other operational energy as well.

2.2.2 The thermal performance provisions of the Building Code of Australia

Prior to 2010 the performance objective of the energy efficiency provisions of the BCA made no reference to greenhouse gas emissions. In 2010 this changed. Performance Objective 02.6 of the 2010 BCA (Volume 2) is 'to reduce greenhouse gas emissions by using energy efficiently' (BCA 2010). Figure 2.3 **Breakdown of home energy u** and Figure 4.2 **Breakdown of home GHG emissions**below show the breakdown of home energy use, and the corresponding greenhouse gas (GHG) emissions for each of those uses, respectively. For the average Australian home, space heating and cooling makes up about 38% of its total energy use which represents about 20% of its total greenhouse gas emissions (DEH 2008). In Tasmania, 50% of energy used in average home is for space-conditioning, (Energy Efficient Strategies 2008) most of which is used for heating. The discrepancy between the figures is due to the variety of fuel types used for heating and cooling. Gas and electricity are the main fuels used for heating and cooling of Australian homes, in about equal proportions, though the greenhouse emissions intensity of gas is about one-third of coal-generated electricity. On the other hand, while less energy is used in water heating (about 25%) than for space heating and cooling it is responsible for more greenhouse gas emissions (23%) This is because most water heaters are inefficient electric heaters (AGO 1999).[1]

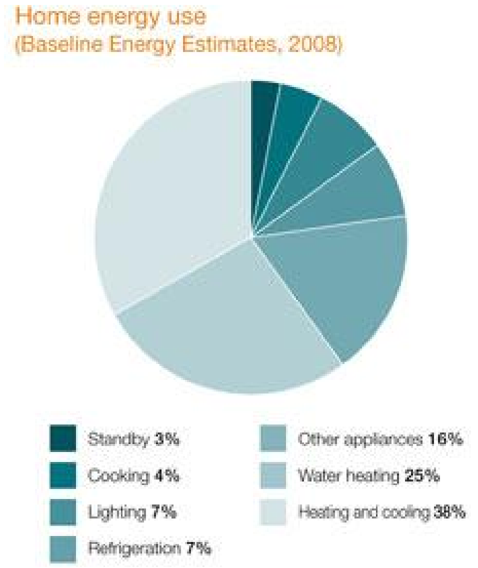

Figure 2.3 Breakdown of home energy use
Source: AGO (1999)

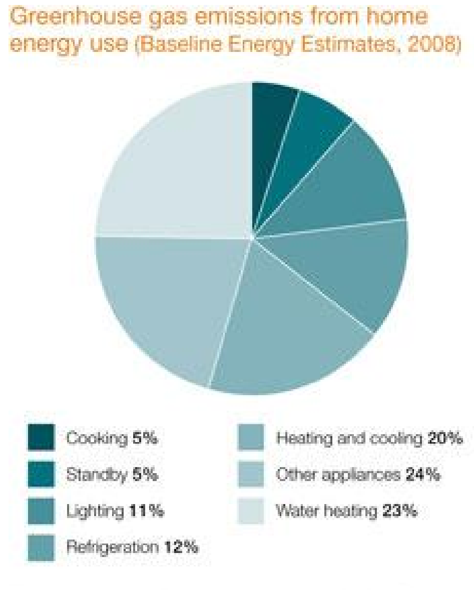

Figure 4.2 Breakdown of home GHG emissions

Consequently, the energy provisions of the BCA currently address about one-fifth of the total GHG emissions of homes built since the regulations were introduced. Given that a vast majority of Australia's housing stock pre-dates thermal performance regulations, and that the final consumption of energy by Australian households is 13% of total final energy consumption (ABARES 2009) the reduction in greenhouse gas emissions thermal performance regulations will provide in the next few years is negligible.

However, it is predicted that by 2020 the number of occupied residential households in Australia will have increased by about 25% (National Housing Industry Supply Council 2009). In addition, by 2036, it is predicted Sydney will need more than a million new homes (Frew 2008**).** Therefore, in the longer term, increasingly stringent thermal performance standards could have a significant impact on total greenhouse gas emissions.

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[1] These proportions will change as electric water heaters are being phased out in all states/territories except Tasmania

2.2.3 Resistance to thermal performance regulations

The introduction of thermal performance regulations, and subsequent increases in the required minimum level, has been not seamless. Building industry groups as well as manufacturers of building materials have objected to the regulations. Resistance has largely been based on arguments about cost. However, concern has also been expressed that higher levels of thermal performance favour some materials and methods over others.

In Victoria, the Housing Industry Association (HIA) stated that increasing the minimum thermal performance regulations from 4 to 5 stars would reduce housing affordability. “The HIA is strongly opposed to the introduction of ill-considered, unsubstantiated and costly energy regulations to the residential building industry” (2005). They also questioned whether energy efficiency measures were economically feasible in the long-term. In regards to the proposed national 6 star standard, the Master Builders Association (MBA) of Victoria claimed it would add $10,000 to the cost of a new house making it “one of the most significant blows to housing affordability in the past decade" (ABC Radio 2009).

Similar concern was expressed by the HIA in Tasmania. They claimed that the state government’s decision to increase the minimum thermal performance from 4 to 5 star would add $8,000-15,000 to the cost of the average new home. The decision “ignores overwhelming independent evidence that costs to the home buyers are greater than predicted by regulators.” In addition, the HIA claimed that the increase in thermal performance would lead to the demise of popular house designs (Stateline Tasmania ABC 2006). Since those claims were made the 5-star regulation was introduced in 2010. There is no evidence that house prices have increased to the extent that the HIA claimed they would, nor is there evidence that the house designs have changed appreciably. In November 2011, the Tasmania State government announced that it would delay the introduction of 6-star regulations (slated to commence in 2012) because of concerns expressed by industry on the affect higher standards would have on housing affordability (Tasmania Government 2011).

The Building Product Industry Council (BPIC) said that they supported improved thermal performance standards provided they were assessed on a scientifically sound basis and housing affordability was not compromised (Green 2011).

The costs associated with thermal performance regulations claimed by those who oppose them are considerably higher than the cost estimates of those who favour regulations. However, Isaacs observed (Tony Isaacs Consulting 2006) that unlike reports undertaken by the Sustainable Energy Authority Victoria (SEAV) and the Australian Building Codes Board (ABCB), the HIA's estimates were never made available for public scrutiny. A study by the Victorian Government of houses built to the 5-star regulations showed that the additional cost to achieve 5 stars was around 2% of total building costs, less than the 3-5% anticipated, and substantially less than what was claimed by the HIA (Victoria Building Commission 2003). As well as thermal performance improvements, this additional cost also included either water savings measures or solar hot water installation. Therefore the cost of the thermal performance measures only would have been less than 2%.

When 5-star regulations were introduced in WA, the state government said compliance would add less than 1% to construction costs (DHW 2006). However, the government acknowledges that for some building sites achieving the 5 star rating would be easier than for others. Similarly in Queensland, prior to the introduction of 5-star regulations in 2009 the state government calculated that compliance would cost less than 1% of construction costs, which would be repaid in 4.5-5 years through savings in energy bills (DIP 2009).

Irrespective of whether the MBA and Housing Industry Association (HIA) have overstated the affect thermal performance regulations will have on housing affordability, it is understandable that there is a reluctance to embrace new thermal performance standards. Objections to higher thermal performance standards may have more to do with a reluctance to change the status quo than concern about prohibitive costs.

The other main concern about thermal performance regulations is that they favour some materials over others. When 5-star regulations were introduced in Victoria, there was anecdotal evidence that the number of new houses being constructed with timber sub-floors decreased because of the perception by builders that 5 stars could be easily and cost effectively achieved by building houses on a concrete slab. However, the trend to concrete slab floors had been increasing steadily since the 1970s, well before thermal performance regulations were introduced (Williamson 1997). The rapid decline in the use of timber floors coincided with an increase in the use for timber stud walls for brick veneer walls in residential construction (Pullen 2007).

Prior to the introduction of 5-star rating in Queensland, Timber Queensland said it would be “impossible for many timber homes to get 5 stars” (2005). The reasons for this were not made clear. HIA Tasmania also claimed that the introduction of 5 star thermal performance requirements would mean that timber floors would become a “thing of the past’ adding that energy efficiency regulations overlook the embodied greenhouse gas emissions of building products.

The Timber Promotion Council (TPC) (2005) in a submission to the Victorian Competition and Efficiency Commission’s 2005 enquiry into energy efficiency suggested that embodied energy of materials should be considered in any assessment of a house’s greenhouse gas emissions. They claimed that a 5-star house with a concrete slab would have more greenhouse gas emissions over its life than a timber floor house with a lower star rating because of the concrete slab’s additional embodied emissions.

Countering the timber industry’s claims, the Cement, Concrete and Aggregates Australia (CCAA) in a submission to the Victorian Competition and Efficiency Commission 2005 said that if regulations were to extend beyond the operational energy of a house to include embodied energy then they should include life cycle energy. The CCAA noted that the use of concrete’s thermal mass could lead to a reduction in energy required for heating and cooling, offsetting its additional embodied energy.

2.2.4 The future of thermal performance regulations

The resistance to thermal performance requirements to date has concerned the increase to 5-star ratings and in some states 6-star ratings. At a 2009 Council of Australian Governments (COAG) meeting it was agreed that houses built after May 2011 will need to meet six-star thermal performance requirements, as part of a plan to reduce the nation's greenhouse gas emissions. However, Tasmania has deferred the adoption of 6-stars until at 2013. An aim of the National Buildings Framework, formed under *National Strategy on Energy Efficiency* (2009), is to "set increasingly strong minimum performance standards over time…with standards to be reviewed and increased regularly, for example every 3 years". Some (Liso et al 2007, Boardman 2007) argue that the successful implementation of changes to regulation is more likely if moderate levels of improvement are introduced gradually.

The introduction of energy efficiency requirements in the BCA in 2003, and each subsequent increase in stringency level, has gone through a Regulatory Impact Statement (RIS) process. One of the purposes of a RIS is to determine whether new standards will be cost effective to the home-owner, That is, over the life of a house, does the money saved by using less energy outweigh the costs of the thermal performance improvements. To date, the answer has been in the affirmative and further increases in the minimum level of housing thermal performance standards are likely if this continues to be the case. Horne and Hayles (2009) note that thermal performance standards in Australia are modest compared to those in some European countries and North America standards where the equivalent of a 7-8 star ratings is mandatory.

It is possible that the same as well as additional concerns will be raised each time an increase in the minimum thermal performance is proposed. Whether higher thermal performance will continue to favour (real or perceived) the use of particular materials and result in significant increases in capital cost is unclear. In regards to the cost of achieving a certain star rating, this will vary across climate zones. However, in cooler climates, such as that in Tasmania, it is recognised that thermal performance improvements are likely to be more cost effective than they are in milder climates because there is a greater potential to reduce energy consumption (Pitt & Sherry 2009).

2.2.5 Complying with thermal performance regulations

There are three methods that can be used to comply with the thermal performance regulations of the BCA. They are:

(1) Deemed-to-Satisfy (DTS) provisions of the BCA; or
(2) Using an Alternative Solution; or
(3) Providing expert evidence that the performance requirements of the BCA can be met.

The DTS energy efficiency provisions for thermal performance cover five main areas: building fabric, solar radiation, building sealing, and air movement (and more recently lighting and hot water). The requirement for each one depends on the climate zone in which the house is located. The BCA has classified 8 climate zones in Australia, each being based on having a range of similar climatic characteristics.

Alternative Solutions are usually ones that are verified using thermal performance simulation software. If a house does not comply with the DTS provisions of the BCA, or meet the minimum star-rating requirement as measured using simulation software, an expert, under the third method, may be able to prove that the performance requirement of the BCA can still met.

Simulation software

Thermal simulation software needs to be approved and accredited by federal and state governments and endorsed by the Association of Building Sustainability Assessors (ABSA). Currently there are three accredited 2nd generation software assessment tools in Australia: AccuRate, BersPro and FirstRate 5.

In rating mode, the approved softwares use standardized, or default, occupancy profiles that define the periods of occupancy, occupant behaviour and preferred levels of thermal comfort. To achieve a thermal performance rating that complies with the relevant regulations, simulations of house designs must adopt these assumptions.

AccuRate assumes living, living/kitchen and bedrooms zones are conditioned, that is, they are heated and cooled for certain periods of the day. It is the calculated heating/cooling requirement of the conditioned area that determines the star-rating of a house design. For living and living/dining zones it is assumed they are conditioned for 17 hours a day while for bedrooms it is for 19 hours a day. AccuRate calculates the energy needed to heat/cool these zones if their temperatures fall and/or rise outside the thermal comfort range during the assumed times of occupancy. Assumptions are also made about the heat gains from cooking appliances within the living/kitchen zone.

All 2nd generation software tools use an area correction factor when calculating the energy rating for a house design. The purpose of the factor is to account for smaller houses having a greater external surface area compared to the floor area than larger houses since the larger the surface area, the greater the heat-flow through the building fabric. Star ratings are based on the area corrected usage rather than the actual predicted energy usage. Energy usage is expressed as MJ/m^2 of conditioned floor area per annum. Table 2.1 shows the area adjusted star band score thresholds (from 5-10 stars) for each capital city in Australia. Star bands are set for each climate zone taking into account the extremes of the local weather conditions with the table showing that the thresholds vary considerably between capital city climate zones.

Table 2.1 Area adjusted star band score thresholds (MJ/m^2.a)

	5 star	6 star	7 star	8 star	9 star	10 star
Sydney	112	87	66	44	23	7
Melbourne	165	125	91	58	27	1
Brisbane	55	43	34	25	17	10
Adelaide	125	96	70	46	22	3
Perth	89	70	52	34	17	4
Hobart	202	155	113	71	31	0
Darwin	413	349	285	22	140	119
Canberra	216	165	120	77	35	2
			MJ/m^2.a			

Source: http://www.nathers.gov.au/about/pubs/starbands.pdf

When using accredited software to assess thermal performance, ABSA lists National Simulation Protocols that must be followed. These include, but are not limited to, the following:

- Using the correct address and climate zone of the house be assessed;
- Using only construction materials embedded in the software;
- Using insulation that is installed in accordance with the BCA;
- Conforming to zoning requirements and the circumstances under which zones are heated and cooled and;
- Performing assessments within the published limitations of the approved software used.

Shortcomings and criticisms of simulation software

Assumptions made about occupancy patterns, behaviours and levels of thermal comfort may not hold true for individual households. This means that predicted energy needed for heating and cooling will not necessarily match actual energy usage. This is a consequence of human behavioural differences, the complexity of modeling buildings and software limitations. The issue of predicted versus actual energy usage is discussed further in section 3.4.4 of Chapter 3. In the case of AccuRate, ratings state explicitly that the calculated energy requirements are for rating purposes only, and should not be used to infer energy usage. However, star ratings have been used as a proxy for actual energy usage in many studies.

Simulation software also assumes that buildings are artificially heated and cooled. This assumption has been criticised and shown to discriminate against houses in mild climates that are designed to be passively heated and/or cooled (Kordjamshidi 2007, Soebarto and Williamson 2001). Soebarto et al (2006) looked at the thermal performance of 3 architect-designed houses built before thermal performance regulations were introduced. Although they would not conform to current energy efficiency standards the occupants reported being thermally comfortable while still using less energy for space-conditioning than a standard house. Kordjamshidi et al (2006) note that in benign climates, a house's energy efficiency is completely dominated by occupant behaviour.

The Timber Promotion Council (2005) criticised software rating tools for their bias to high thermal mass materials. Conversely, the brick industry (2005) claimed that software favours lightweight construction adding that a metric need to be developed that considers a material's thermal mass as well as its R-value. The Renewable Energy Council (2006) noted that both the TPC and brick industry couldn't be right. Dewsbury (2011) in a study to validate AccuRate found there were differences between the predicted and actual temperatures for both slab-on-ground and timber floor houses.

2.3 DO ENERGY EFFICIENCY REGULATIONS WORK?

As previously mentioned, the aim of setting minimum thermal performance requirements is to reduce greenhouse gas emissions. However, the effectiveness of thermal performance, and other energy efficiency regulations, in achieving that goal has been questioned. The Productivity Commission (2005) recommended that more stringent energy efficiency standards should not be introduced for residential buildings until the existing standards were fully evaluated and shown to meet their aim. While standards have been increased since then, in 2011 the Department Climate Change and Energy Efficiency commissioned a study to compare the actual energy use of 4-star houses with the actual energy use of 5-

star houses.[2] Williamson (1997) observed that improving thermal performance and reducing the life cycle greenhouse gas emissions of houses may in fact be contradictory goals. While he did not explain the circumstances that could lead to this, there are several possibilities:

(i) A house's energy supply could be wholly, or partly, generated from renewable energy, which has no or low greenhouse gas emissions. Therefore the embodied greenhouse gas emissions associated with thermal performance improvement could outweigh any reduction in operational emissions it provides.

(ii) A house may be passively designed, and have occupants who do not use artificial heating/cooling. Improving a house's thermal performance may add to embodied emissions, and therefore life cycle emissions, as there is no reduction in heating/cooling emissions to be made.

(iii) At some stage after a house is built, grid energy becomes less CO_2 intensive (an aim of federal government's renewable energy target); depending on what stage of a house's life that this occurred, embodied CO_2 emissions of the thermal performance improvement could outweigh any savings in heating/cooling CO_2 emissions.

(iv) The choice of heating system is a factor: Joelsson and Gustvasson (2009) found that the efficiency of the heating system had a greater influence on primary energy use than house envelope measures. Furthermore, a house built to achieve a high level of thermal performance may use a heating system which is more carbon intensive than a heater used in a house with a lower level of thermal performance (e.g electric versus gas heating) While less energy may be used for heating in the house with the higher thermal performance level, the resultant CO_2 emissions could be higher. In Tasmania approximately 28% of houses use wood as their primary source of heating, and approximately 66% use electricity (ABS 2011).

[2] The study was due for completion by the end of 2012

A number of economists (Brookes 1990, Rees 1995) argue that improving energy efficiency at a micro-level actually increases energy consumption at a macro-level. This is due to the 'rebound effect' whereby money saved by households through energy efficiency measures is spent on other goods. Others (Horvath 2004) reject this view while Herring (1999) says that like most economic questions it is impossible to prove either way.

Some (Shellenberger and Nordhaus 2008, Herring 1999) question whether regulations alone are enough to address the problem of greenhouse gas emissions, particularly as population will increase and the standard of living of developing countries will rise. Even if energy is used more efficiently, worldwide consumption of energy may triple by 2050, at a time that it needs to be reduced by about 50% to stabilise global warming. Nordhaus and Shellenberger (2008) believe the main focus should be on investing in cleaner energy technologies, not on using energy efficiently. This is a view shared by Lomborg (2007) who also questions claims about the cost effectiveness of cutting greenhouse gas emissions. The economic costs from carbon taxes imposed of CO_2 reduction far exceed the benefits (avoided damage) they provide from lower resultant temperatures (Nordhaus in Lomborg 2007). However, Herring (1999) believes that cost effective energy efficiency measures will make it possible for people to more easily afford the shift to more expensive renewable fuels. Others (Lee & Yik, 2004) suggest that the best way to reduce greenhouse gas emission is through a policy mix that includes carbon taxes, energy efficiency measures and the use of renewable energy.

Another factor that will result in energy savings at the household level having no effect at the macro-level is the introduction of an Emissions Trading Scheme (ETS) (Australia Institute 2008), which will replace the carbon tax in 2015. The aim of the scheme is to put a cost on carbon emissions, thus encouraging the uptake of cleaner energy technologies. Under the Scheme, the federal government would set a cap on the total amount of carbon that industries covered under the scheme can emit. Permits are issued to the annual cap each year. Polluting industries will need to acquire a permit for every tonne of carbon they emit, with companies competing in the market for the permits they require. However, saving energy at a household level provides energy producers (one of the biggest emitters of greenhouse gases) and local manufacturers of energy intensive building materials, such as aluminium and cement, more opportunity to emit up to their permitted cap. As the carbon tax legislation currently stands, saving greenhouse gas emissions through improved thermal performance, or even choosing materials with a lower embodied energy than alternative, will have no effect on the nation's total emissions. The Wilken's Strategic Review of Australian Government Programs (2008) noted that under an ETS it is the composition of CO_2-e abatement that changes, not the amount. The lack of complementarity between thermal performance regulations and the ETS is considered a serious policy flaw.

2.4 EMBODIED ENERGY

Section 2.2.3 outlined the resistance by certain industry sectors to thermal performance regulations, one of which was that only energy for heating/cooling was regulated, and not embodied energy. This section explains what embodied is, how it is measured, and its significance in the life-cycle energy of a house.

2.4.1 Embodied energy and how is it measured

The embodied energy of a material or product is the total energy used in its production including upstream activities such a raw material extraction, transport, manufacturing and assembly (Pullen 2007). It comprises direct and indirect energy. The direct energy is the energy used in the manufacturing process whereas indirect energy is the energy used to produce the goods, other materials, and services required for that manufacturing process to occur.

Numerous studies (Pullen 2007, Treloar et al 2001, Noller 2006, Crawford 2005, Baird et al 1997) have shown that differences in embodied energy figures for individual building products, (or m^2 of building), are due largely to methodological differences in how embodied energy is calculated. However, they all show that process based figures are lower than those obtained using hybrid methods. While the method used is less important when comparing which materials have a higher embodied energy, it becomes more important when calculating its contribution to life cycle energy.

There are a several methods used which vary in the comprehensiveness of the system boundaries selected for the analysis. Others (Crawford 2005, Lenzen 2002, Treloar 2000) have described in detail the difference between the methods. A summary of each method, and their advantages and disadvantages, is given below.

Process analysis

Process analysis usually only involves the calculation of the direct energy used in the manufacturing process. In that case, the energy system boundary of process analysis is limited to that which occurs within the boundary of the factory, or manufacturing plant. For some manufacturing processes, such as metals production the direct energy can amount to more than 50% of the total energy consumed (sum of direct and indirect energy), while for other products such as concrete and timber, the direct energy is a much lower proportion due to significant energy inputs in upstream raw materials manufacture (Crawford 2005). Further process analysis can be undertaken, for example of the material inputs into the main product, but this becomes increasingly time-consuming and is rarely undertaken. Process analysis is generally seen as accurate but only within the boundaries that energy is being measured. However, because of this finite boundary system, process analysis can be over 50% incomplete because significant energy contribution outside this boundary can be omitted (Treloar 2000).

Input-output analysis.

Input-output analysis is another method used to estimate embodied energy and uses national average economic data for each sector of the economy. Input-Output (I-O) tables, produced by the Australian Bureau of Statistics every few years, show the direct fiscal inputs for each industrial sector of the Australian economy. Researchers have combined these tables with national energy data from the Australian Bureau of Agricultural and Resource Economics (ABARE) to develop an energy-based I-O model of the economy. The I-O tables are divided into the sectors of the Australian economy, each having a respective direct energy intensity and total energy intensity expressed in GJ/$ of product. This includes all the direct and indirect inputs of energy from every other sector. It is considered more comprehensive than process analysis because it has a systemically complete boundary system, accounting for both direct and indirect energy inputs (Treloar 1997, 1998: Lenzen, 2002, Crawford 2005). There are, however, disadvantages (Pullen 2007). The method uses national average costs for energy, but the price paid for materials by manufacturers is likely to vary, and in many cases be lower. Lower energy prices would have the effect of raising embodied energy coefficients. In addition, the method uses average energy intensities for a particular industrial sector of the economy. In reality, the energy intensity of sub-groups within that sector is likely to vary.

Hybrid analyses

Due to the limitations of both process analysis and input-output analysis, researchers have developed hybrid approaches. There are two types of hybrid analysis: process based analysis and I-O based analysis.

In process based hybrid analysis, for direct energy, the embodied energy of the individual material inputs are calculated from process analysis and I-O tables are used to calculate indirect energy. These are summed in proportion to the material quantities in the product (Pullen 2007). This type of analysis is more complete than the methods described above. However, as the supply chain is disaggregated to allow the integration of process data, there is the potential that downstream and sideways energy inputs are overlooked Extending the system boundary does not reduce the error to an acceptable level because of the complexity of the supply chain that would have to be investigated (Crawford 2005). The truncation of downstream and sideways energy inputs is depicted in figure 2.3 below.

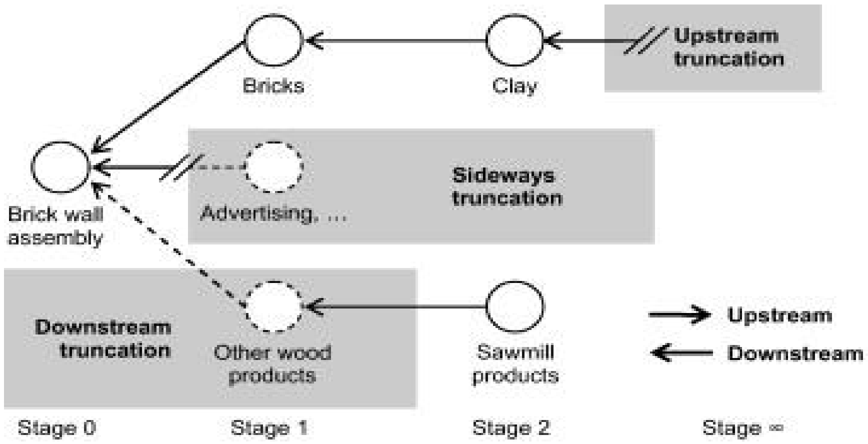

Figure 2.3 – Truncation of downstream and sideways energy inputs

Source: Crawford, R (2010)

Input-output-based hybrid analysis was developed by Treloar et al (2001) and is currently the preferred method for embodied energy analysis of Australian buildings and building materials because it is more complete than other methods (Crawford 2005). This method addresses the problems of process-based analysis by starting with a disaggregated input-output model to which available process data is integrated. This avoids the possibility for sideways and downstream truncation errors discussed above, in addition to upstream truncation. The direct inputs to a specific product or process are calculated using process analysis. Upstream indirect processes can be accounted for by further process analysis or I-O analysis if it is considered too difficult or time consuming to collect relative to the significance of the process in question. The steps involved in I-O based hybrid analysis are summarized as follows:

(i) Extract the inputs from the relevant sector of the economy from which the product belongs.

(ii) Identify the inputs that have been calculated using process based analysis.

(iii) The total energy intensity of each of the inputs represented in the process analysis is subtracted for the total energy intensity of the sector.

(iv) The remainder of the unmodified inputs (the total energy intensity of the sector minus those inputs subtracted, in GJ/$1000) are then multiplied by the price of the product ($) and divided by 1000 to give the additional embodied energy for the product, in GJ.

(v) The process based hybrid analysis figure is then added to this figure, minus the direct energy component (this is included in the remainder of the unmodified inputs) to give the I-O based hybrid analysis embodied energy total:

$$EEt = Q_M \times W \times EI_M + (TEIn - TEI_M) \times \$BP/1000 \text{ (ref)}$$

where *EEt* is the total embodied energy through I-O based hybrid analysis, Q_M the quantity of materials in the basic product, *W* the wastage multiplier of the respective material, EI_M the material hybrid energy intensity, *TEIn* the total energy intensity of the I-O sector n, TEI_M the total energy intensity of the I-O path representing the basic material, and $BP the total price of the basic product.

2.4.2 The significance of embodied energy

Life cycle energy analysis (LCEA) of houses is a form of life cycle assessment, which focuses specifically on energy consumption and/or associated greenhouse gas emissions. Typically, it takes a cradle-to-grave approach whereby the energy associated with a house's manufacture and use phase is assessed up to its end of life. The contribution of embodied energy to life cycle energy has generally been considered insignificant compared to contribution of operational energy. However, as more comprehensive methods of calculating embodied energy have been developed, the actual significance of embodied energy has been understood. Numerous housing LCEA studies have shown this is the case. Treloar et al (2001) found that embodied energy was approximately half of operational energy over a 30-year life. Mackley (1998) showed that savings in operational energy can be outstripped by embodied energy over a house's life. Thormark (2006) notes that embodied energy can account for 40-60% of total energy use for low energy house over an assumed service life of 50 years.

If embodied energy can comprise half or even 80% of total operational energy over a house's life, then given the breakdown of household energy use in figure 2.1, it follows that embodied energy could exceed the energy used for heating and cooling. Furthermore, rather than comparing their relative energy contributions, if embodied CO_2 emissions and the CO_2 emissions associated with heating/cooling are compared, embodied emissions are more likely to exceed heating/cooling emissions.

2.5 REDUCING ENERGY AND CO_2 EMISSIONS THROUGH MATERIAL SUBSTITUTION

Given that embodied energy can contribute significantly to life cycle energy, it follows there are opportunities to reduce life cycle energy by choosing a material with a lower embodied energy than a functional equivalent. Moreover, by converting operational and embodied energy to greenhouse gas emission equivalents, life cycle greenhouse gas emissions can also be reduced.

Noller (2005) found that up to 30% embodied energy abatement was possible for commercial buildings with the structure, façade and floor coverings offering the greatest abatement opportunities. The study concluded there were more, low cost opportunities to reduce a commercial building's life cycle greenhouse gas emissions through embodied emission abatement than by complying with the BCA's regulations for operational energy. However, this is complicated by the 'churn' rate of commercial buildings which adds significantly the buildings embodied energy over its lifetime.

Borjesson and Gustavsson (2000) compared the life cycle greenhouse gas emissions of using timber and concrete frames for multi-storey construction. The timber frame had a 60-80% lower primary energy input than the concrete frame and lower life cycle input than the concrete frame. Upton et al (2008) found for thermally comparable houses, using timber based systems over concrete or steel alternatives produced 20-50% fewer greenhouse gas emissions over a 100-year life. A similar study by Gerilla et al (2007) also found using timber instead of reinforced concrete reduced life cycle emissions. Gustavsson and Sathre (2009) concluded that the use of timber as a building material instead of concrete is an effective way of reducing CO_2 emissions. Others (Berg and Lindholm 2005, Cole 1999, Glover 2003, Gonzalez and Navarro 2006) have also found that in terms of minimising life cycle emissions, timber is a better alternative than other functionally equivalent building materials. However, Perez-Garcia and Lippke (2005) and Puettman and Wilson (2005) note the results of studies such as these are sensitive to a number of assumptions, in particular end of life scenarios for the respective materials.

Petersen and Solberg (2002) showed that the life cycle greenhouse emissions associated with the steel and timber glue laminated (glulam) beams varied significantly depending on assumptions made about their production and waste handling at the end of life. Depending on assumptions made about the end of life of functionally equivalent building materials, the ranking of which one is preferable in terms of greenhouse gas mitigation, can be reversed. For example, if steel is manufactured from scrap rather than from ore much less energy is needed. Similarly, if timber is landfilled after demolition rather than used as a fossil fuel substitute, greenhouse gas emissions associated with its life are higher because of the methane released as the timber decays. Therefore, the steel may have more avoided CO_2 emissions if it replaces ore at the end of its life and the glulam timber is landfilled.

Crawford (2009) found that under a number of end-of-life scenarios concrete railway sleepers had lower lifecycle CO_2 emissions than timber sleepers. Similarly, Treloar (2000) found that for certain scenarios the life cycle greenhouse gas emissions of timber may be higher than steel. These included when recycled steel is used and the timber is landfilled after demolition (the landfilled timber emits methane as it decomposes). Noller (2005) also found that using recycled steel and other recycled products was one of the most effective ways to reduce a building's total embodied energy.

As well as end-of-life scenarios affecting the life cycle energy (or CO_2 emissions) associated with certain materials, so too can materials' recurrent embodied energy. Over the life of a building, there are building products and materials that require maintenance and/or replacement for which the associated energy is termed *recurrent* embodied energy. Treloar (2000) estimates that recurrent embodied energy can be about 32% of initial embodied energy, depending on the materials and products used. While a material may have a lower initial embodied energy than a functionally equivalent material, it may have higher life cycle energy because of its associated recurrent embodied energy. Therefore, higher embodied energy materials may provide better life cycle energy outcomes.

2.6 THE RELATIONSHIP BETWEEN EMBODIED ENERGY AND THERMAL PERFORMANCE

The studies described in the previous section assumed that substituting functionally equivalent building materials had no effect on the thermal performance of a building. However, this is not always the case. Several studies have looked at the embodied energy of different building assemblies and their effect on energy for space-conditioning. Crawford et al (2009) showed that for Melbourne's climate, a concrete floor house had lower life cycle energy than a timber floor house over a 50-year life. The initial and recurrent embodied energy of each floor type, and the influence they had on operational energy were taken into account. Both floors were un-insulated; typical of floors built to meet the minimum thermal performance requirements of the day. That the concrete floor had lower life cycle energy than the suspended timber floor is in part due to the debatable assumption that the timber floor would require significant maintenance/replacement requirements after 25 years. However, given that suspended timber floors built to BCA requirements are not exposed to the weather or in contact with the ground, maintenance/replacement after 25 years is unlikely.

In a study of the life cycle energy implications of different wall systems in a cool climate, Pierquet *et al.* (1998) found that in general as embodied energy of the wall system increased, the heating requirement decreased. Recurrent embodied energy associated with each of the wall systems was not included but was acknowledged by the authors as being important.

Fay (1999) looked at the life-cycle energy of different housing types in Melbourne and found that life-cycle energy requirements were strongly influenced by their individual design and construction characteristics. These included, amongst other things, window size, thermal mass, insulation levels and ventilation rates.

Hacker et al (2007) studied how thermal mass affects the balance between embodied and operational energy. The study involved a case study house located in England. While the size, shape, orientation and R-values of the house remained the same, the level of thermal mass was varied from lightweight to heavyweight construction. In each case the embodied and operational CO_2 emissions were calculated to give total life cycle CO_2 emissions. While increasing the thermal mass increased the house's embodied CO_2 emissions it reduced its life cycle CO_2 emissions because less energy was required for heating and cooling. Compared to the lightweight house, the medium, medium-heavy and heavy construction type paid back the additional embodied energy within 11, 21 and 23 years respectively. Once this was paid back, their life cycle emissions were lower than the lightweight house. However, Tuohy and McElory (2004) commenting on thermal mass, noted that the one-size fits all advice is often inappropriate. The effect of thermal mass varies with insulation levels, climate, orientation, and occupancy patterns. The higher the latitude the less effective it is, and at latitudes higher than 47º it can have a detrimental effect on space-heating. In terms of life-cycle energy, there are cases where lightweight buildings may be more appropriate.

Most LCEA involve changing variables, such as materials, of houses that are designed to meet the thermal performance requirements of the day. The study of the effect of incremental improvements in thermal performance improvements on LCE is less common. Hernandez and Kelly (2008) examined the implications on the life cycle energy of a house, in a temperate climate, of various thermal performance improvements. They found that over a 50-year life certain insulating materials could actually increase a house's life cycle energy. They noted that orientation and opening size would be more beneficial from a life cycle energy perspective than more materials. Fay et al (2000) note that in terms of reducing life-cycle energy, there may better strategies than the addition of higher levels of insulation because of its embodied energy.

While the choice of floor material can affect the life cycle CO_2-e of a house so too can the choice of insulating material and where it is located. For most climates installing floor insulation improves a house's thermal performance. For two uninsulated floor types, it may not be the case that the one with the lowest embodied CO_2 emissions remains so once insulation is added. This will depend on the level of thermal performance being sought and the type of insulation being used.

Thormark (2006) noted that when designing low energy buildings, particular attention needed to be given to the choice of materials to reduce lifecycle energy. Thormark (2006) simulated changes to the framing and insulation levels of the building envelope of houses built to meet the PassivHaus standard to examine the effects on embodied energy. The thermal performance was unaffected by the changes. Depending on the type of insulation and framing method used, the embodied energy varied from between -17% to +6%. It was concluded that for some low energy houses, that some materials might increase a house's life cycle energy.

2.7 CONCLUSION

This Chapter described the history of housing thermal performance regulations in Australia. From a number of voluntary and mandatory schemes across several jurisdictions, thermal performance regulations now extend nationally. An aim of the *National Strategy for Energy Efficiency* is to increase incrementally and progressively minimum thermal performance standards.

Reasons for resistance to the introduction of and subsequent increases in thermal performance regulations were discussed; the main ones being the impact on housing affordability and that regulations may favour some materials over others. In addition, factors that could lead to thermal performance regulations not achieving their objective (reducing greenhouse gas emissions) were also explored. One of those factors was that the additional embodied energy associated with thermally efficient houses might outstrip any savings in space-conditioning energy that has been achieved. The shortcomings and criticisms of rating tools and the significance of embodied energy in the life-cycle energy of houses were also discussed. The following chapter will review the literature on the design implications and capital costs of building thermally efficient houses.

CHAPTER 3 – BUILDING THERMALLY EFFICIENT HOUSES: DESIGN IMPLICATIONS AND CAPITAL COST

3.1 INTRODUCTION

Chapter 2 discussed the purpose and history of housing thermal performance regulations in Australia. Reasons for resistance to the introduction of thermal performance regulations, as well as subsequent increases in the minimum required level, were outlined. One argument against increasing thermal performance regulations is that housing affordability will decrease. Another is that regulations disadvantage materials with low embodied energy, leading some to suggest that regulations should be broadened to include embodied energy. The contribution embodied energy makes to life cycle emissions of housing and how that changes as thermal performance increases were examined.

Sections 3.2 and 3.3 of this Chapter discuss the design implications of higher thermal performance standards and factors that affect the capital costs of energy efficiency measures. Section 3.4 discusses payback periods and life cycle costs associated with housing thermal performance measures. Section 3.5 examines the cost effectiveness of energy efficiency measures in reducing greenhouse gas emissions and identifies the shortcomings of previous analyses.

3.2 DESIGN IMPLICATIONS

In the UK it has been proposed that all new housing be zero carbon by 2016. How that can be achieved economically, and whether it is a realistic goal, is the subject of debate. Lowe (2007) believes a range of options will need to be considered, including improved thermal performance as well as renewable energy production. McManus et al (2010) believe there will be significant cost and design implications and Menon & Porteous (2008) note that there will have to be significant changes to the existing building culture for the zero carbon target to be met. They looked at how to design and build to the European ‘PassivHaus’[3] standard economically. A prototype house was developed with simple geometry and compact form, which made achieving a high level of thermal performance more cost effective relative to conventional houses. They concluded that the prototype house is more cost effective than upgrading the specification of a current industry standard house.

According to Banfill and Peacock (2007) volume builders in the UK, constructing the vast majority of new homes, have very little experience in building to achieve high thermal performance standards. Moreover, they are probably unaware of the methods needed to achieve it. Technical knowledge, regulations and production methods are all aligned to building a certain way, consequently change is hard to implement (Lovell 2005). Building very low energy houses may require wholesale changes to both the materials and methods needed. Similarly in Australia, little is known about the effects high levels of thermal performance will have on the design and buildability of volume-built homes. HIA Tasmania has opposed recommendations to increase the minimum level of thermal performance for houses in that state on the basis that too little is known about how it can be achieved (ABC, Stateline Tasmania 2006). Interestingly, the HIA has also claimed that increasing the minimum level of thermal performance would substantially increase house costs. If little were known about how to achieve higher levels of thermal performance then the extent to which they affect house costs would also be unclear. Consequently, the HIA claim remains unsubstantiated at this stage.

In Finland building energy efficient houses has required little change in the building culture. In contrast to the UK, this may be because the building techniques lend themselves more easily to improved thermal performance and the level of increase in thermal performance over standard houses is not as high. In Finland, the objective of what are defined as ‘energy efficient buildings’ is to use 50% less energy for space heating than a house constructed to the National Building Code. In order to achieve this standard, builders

[3] The term PassivHaus refers to a construction standard that assures houses achieve comfortable year-round indoor temperatures without conventional heating. To meet this standard, a house’s heating requirement must not exceed 15 kWh/m^2 per annum. To achieve the PassivHaus standard massive, lightweight and mixed construction types can be used

have tried to streamline the construction process as much as possible using well-known materials, technologies and components. Unfamiliar and risky methods are avoided. Halme et al (2005) note that builders cannot be expected to work through a maze of possible solutions to achieve increased thermal performance. Interestingly, more than 75% of detached houses in Finland are built of timber, which readily achieve minimum thermal performance requirements using a simple thermal insulation system (Halme et al, 2005).

3.3 CAPITAL COSTS

In Australia, building houses that exceed the required minimum level of thermal performance is the exception, not the rule, hence little is known about the methods and materials required to do so. Therefore it follows that there is uncertainty about costs. However, some believe that any increase in cost would be insignificant. Carrad et al (2008) and Price and Soebarto (2005) note that the perceived cost of energy efficient buildings is likely to be significantly higher than actual costs. Bartlett & Howard (2000) believe that quantity surveyors typically overestimate the costs of energy efficiency measures and underestimate the energy savings they will provide. Others (Menon and Porteous 2005) have concluded that low energy improvements for housing are not necessarily cost prohibitive. In Finland, higher thermal performance standards led to a 0-5% increase in building costs, less than the increase perceived by industry (Halme et al 2005).

Claims that energy efficient houses can be built for little or no extra cost, as well as claims to the contrary, are often unsubstantiated or potentially biased by sectorial interests. In any case, stating that housing energy efficiency measures cost a certain amount, or represents a certain proportion of total building costs, can be misleading. The cost of increasing the energy efficiency of houses is influenced by a number of factors. These include house type and size, prevailing climate, site characteristics, the level of energy efficiency that is being sought, and whether total household energy or energy for space conditioning is being addressed. Before meaningful conclusions about the costs of energy efficiency can be made, the questions “energy efficient compared to what?” and “cost compared to what?” need to be addressed.

Furthermore, a number of factors influence the contract price. Prices of materials fluctuate (for example steel, aluminium and copper are particularly prone to price fluctuations); the prevailing economic conditions change (when the economy and housing sector is strong for example, builders tend to be busier and their prices tend to be higher); the financial circumstances of individual builders change; while the size of the builder of the builder can also affect costs (larger builders can bulk purchase materials). The cost of thermal performance improvements (as distinct from the cost of other building elements) is likely to be influenced by one or more of these factors. In the UK, it has been observed that the cost of complying with the Code for Sustainable Homes (CSH) will differ for every house builder (Osmani and O'Reilly, 2009)

3.3.1 Economies of scale and industry learning

The extent to which thermal performance improvements increase the capital cost of houses is obviously the subject of debate. However, over time the relative cost of achieving a certain level of thermal performance is likely to fall as the uptake of measures necessary to meet the standard increases, and the products, equipment and building practices become commonplace. It is estimated that the costs of goods generally decrease by 10-30% with every doubling of their application (Jakob 2006, Pears 2004). Consequently, even if construction costs do increase when higher thermal performance standards are introduced, the cost of improvements should decrease as their use becomes more widespread. There is evidence that this is the case. The introduction of insulation regulations in Victoria in 1991 saw the cost of insulation fall because of increased demand (Tony Isaacs Consulting 2005). Similarly, as government regulations have been successful in moving energy efficient appliances into the mainstream, increased sales has led to lower manufacturing costs which has been reflected in their price (Ellis et al 2007). Figure 3.1 below shows how the cost of photovoltaic (PV) systems has fallen dramatically in recent years as production has increased, and how it is predicted to decline further in future years.

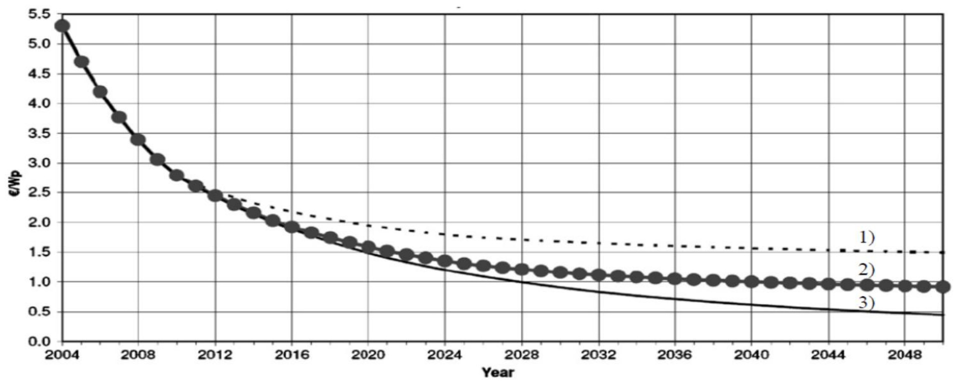

Figure 3.1 -Projected Reductions in Building Integrated PV Systems to 2050 Notes: Scenario 1 'pessimistic'; Scenario 2 'optimistic/realistic'; Scenario 3: 'optimistic/technology breakthrough'

Source: Hearps & McConnell (2011) Renewable Energy Technology Cost Review, Melbourne Energy Institute, Technical Paper Series

Pears (2004) points out that in regions where double-glazed windows are standard, their cost is similar or even lower than single glazed units. In Switzerland very highly efficient triple glazed windows are a comparable cost per m^2 as standard windows (Jakob, 2006). It follows that the cost of other products that improve the thermal performance of buildings would also fall. For large housing developments built to the PassivHaus standard additional costs were lower than for one-off developments because manufacturers could mass-produce materials required to meet the standard (Schneiders and Hermelink, 2006)

In the UK, it has been suggested that houses could reduce their CO_2-e by 60% (described as "the 40% House") by 2050 (Boardman 2007). However, the economic feasibility of achieving such a reduction has been contentious. Hinnells (2005) believes that experience curves as well as energy price scenarios bring the payback of measures down to reasonable levels, thus making the scenario plausible. Experience curves applied to the 40% House scenarios show many new technologies falling to a fraction of their current price. The consequent change in capital costs for measures for the 40% House as a result of learning is shown in Table 3.1 below.

Table 3. 1- Learning rate UK '40% House'

	Solar Hot water	LED Lighting	New insulation material	PV
Current cost	£3,250	£20	£10,000	£12,600
2050 expected cost	£2,328	£5	£2,634	£642

Source: Boardman (2005)

The concept of learning rates is not new. However, research into how it affects the cost of energy efficiency improvements in buildings is relatively recent and there are no studies specific to the Australian building industry. [4]

As previously mentioned, past increases in the minimum thermal performance requirement for new houses have undergone a Regulatory Impact Statement process. The methodology adopted for RISs has been criticised because it assumes costs of energy efficiency measures remains constant over time, whereas in reality they are likely to fall. The Federal government recognises that more accurate estimates of future costs are needed for future RISs, and is proposing to commission a study into building industry learning rates in 2012.

3.3.2 Supply and demand

Economic theory suggests that increased demand for products will cause their costs to fall. However, the demand for energy efficient houses is low. An Australian online survey of prospective home-buyers found that 86% would pay more for a house with 'green' features (Maher 2008). Similarly a UK survey found a majority of prospective home-buyers would pay more for an 'eco-home'. While these results suggest that there is a demand for energy efficient homes, Lovell (2005) notes that willingness-to-pay surveys might overestimate consumer demand, as there is a tendency for people to say what they perceive to be the right thing, in this case, saving energy. Also, the surveys did not differentiate between first,

[4] In 2012 the Australian Department of Climate Change and Energy Efficiency commissioned a study into building industry learning rates. At the time of writing, the report had yet to be been published.

second or third home buyers, or investors. A survey of these individual groups is likely to produce very different results.

Evidence suggests that while people are concerned for the environment, they are likely to adopt more environmentally conscious behaviour only if it is inexpensive (DEH, 2000). That governments offer subsidies for the installation of household energy and water saving measures is, in part, an acknowledgment of consumers' reluctance to pay for them.

The DEH (2005) noted that first home buyers often do not have the resources to invest in more expensive, energy efficient appliances, insulation or quality window coverings but second and third home-buyers are usually in a better financial position to do so. There is a presumption therefore at a government level that energy efficiency appliances and improving thermal efficiency can be prohibitively expensive.

It is argued that the more energy efficient a house, the lower its life cycle costs, leaving the owner better off financially in the long-term. Although there is the potential to recover any additional cost of energy efficient products through lower running costs, Boardman (2004) notes there is little evidence that ordinary consumers consider it as a significant basis of their decision to purchase products. If they did, it would follow there would be greater demand for energy efficient houses. Rising fuel prices are said to explain the trend to more fuel-efficient cars in recent years (Smith 2007). However, fuel-efficient cars, leaving aside those with hybrid or other complex power systems, are generally smaller, and therefore less expensive than less fuel-efficient cars. The reason for their increased sales may have more to do with the lower upfront cost than lower running costs. The extent to which consumers give importance to life-cycle costs would be clearer if fuel-efficient cars were more expensive but the additional cost could quickly be recovered through fuel savings.

Unlike the housing sector, running costs are an important consideration to both building owners and tenants in the commercial property sector. In Australia, owners of existing buildings can use the National Australian Built Environment Rating Scheme (NABERS) to calculate energy use and show running costs to prospective tenants. Rental premises are marketed on the basis of their energy efficiency. Although they command a higher rent, tenants recognize that any additional rent can be more than offset through reduced energy bills (Roussac 2009). However, a house's thermal performance may be a marketable asset according to a study by Berry et al (2008). Since 1999, it has been mandatory to disclose the energy performance of houses sold in the ACT. The study showed that, all other things being equal, a house with a higher thermal performance rating would sell for more than one with a lower rating. The study also notes that the higher value of properties with higher ratings is more than likely to offset the additional cost of the thermal performance improvement. Overseas, there is also evidence that the resale value of more energy efficient homes is higher (Chiras 2004, Neiminen et al cited in Halme et al 2005).

While people may not consider running costs prior to buying a house, there is evidence that they are important once they have moved in. A Swedish study (Brannlund et al 2007) found that when energy prices increased significantly, household energy use fell dramatically. The reduction was greater than when thermal performance standards for Swedish housing increased. Australian households too are more concerned with costs than the environment, but while electricity is relatively cheap, they are generally unconcerned by the amount they consume (DEH 2005).

Most builders are unlikely to see that differentiating themselves in the market, by building houses to achieve higher levels of thermal efficiency, provides any competitive advantage; if there is no demand for energy efficient homes they will not build them (Cunic Constructions 2010). The residential construction industry is characterized by a large number of very small businesses. The average number of people they employ is 1.8 (ABS 2009). Builders of this size are unlikely to build a house to achieve a level of thermal performance higher than what the regulations require because it would be considered a financial risk. The residential building sector is competitive and profit margins are typically small. Most builders would see cost savings, rather than building energy efficient houses, as providing a more competitive advantage.

Change is difficult to implement in the building industry if there are no perceived critical problems within it (Hughes 1987). There is sufficient demand for houses as they are currently built so there is little incentive to change them. Most volume builders have a range of standard designs that comply with the minimum thermal performance regulations.

Improving the thermal performance of their design range would incur an additional cost because of the time and effort involved. Part of this time and effort would entail using simulation software to redesign their houses. A survey of UK builders found that having to change their standard designs to meet new CSH standards was a major reason for their reluctance to embrace them (Osmani and O'Reilly, 2009). However most developers do not use simulation software but rather rely on the deemed-to-satisfy (DTS) provisions of the Building Code of Australia (BCA) (Price and Soebarto 2005).

Stocklands, Lend Lease and Henley homes, all large developers, have however designed and built houses that exceed the minimum thermal performance requirement. Unlike the majority of builders they are better placed to innovate and take financial risks. Furthermore, the cost of thermal performance improvements for large developments is likely to be greatly reduced because of favourable material supplier agreements. These builders have indicated that preempting subsequent increases in thermal performance regulations has provided competitive advantages.

Lovell (2005) suggests that traditional economic demand and supply theory does not apply to housing because it is an atypical consumer good. Unlike comparatively cheaper and more disposable consumer goods, few people experience a wide range of house types. Therefore, most consumers are unaware of the potential benefits that thermally efficient houses can provide. Furthermore, unlike a house's architectural features or its location, elements that improve a house's thermal efficiency are largely unseen and therefore more difficult to market. A survey of people who bought units in a residential building in Germany, which meet the Passive House Standard indicated that a high thermal efficiency was not an important factor in their purchasing decision. More important was that the building was new and that the units had balconies (Schneiders & Hermelink, 2006).

3.3.3 Builder's experience

In pricing a project, builders (and estimators) will make an allowance for risk associated with work for which they are unfamiliar. However, as builders become more familiar with certain methods and materials, costs in the future are likely to fall. Whether that reduced cost is passed on to the client will depend on how competitive the market is. Specialist and highly skilled work for which there are relatively few practitioners is generally more expensive than standard trade work, such as carpentry, bricklaying and plastering. The higher cost is not so much for the material but for labour associated with atypical methods. As it becomes more familiar, and pricing becomes more competitive, costs then fall.

The Business Council for Sustainable Energy (2003) noted that soon after new minimum thermal regulations are introduced there is a learning phase because different skills and techniques are needed. Initially these may incur costs but through experience these will be reduced over time. It is unclear though what new skills and techniques would be required. That would depend on the house type, the level of thermal performance being sought, and the methods chosen to achieve it.

In reference to the UK's increasingly stringent housing energy efficiency regulations, Menon & Porteous (2008) believe associated labour and material costs will come down over time. Feist et al (2005) say that the additional construction cost of building houses to the PassivHaus Standard has fallen about 85% over the last 20 years through better understanding of the techniques involved. Presumably, however, a portion of that reduction could be attributed to the cost of certain components (such as high performance windows) falling as their use became more widespread. A case study of cost effective, energy efficient houses (Mathias & Mathias 2009), found costs were reduced by using a builder with experience in building them. A Leeds Metropolitan University study (2009) involved the design and construction of an energy efficient housing development in the UK. To achieve a high level of thermal performance atypical construction details were for which costs fluctuated. Initially sub-contractors' prices were high, which reflected the inclusion of risk. However, as the project progressed and buildability issues were solved, labour costs tended to fall. The authors of the study also note that for products for which there was market competition, such as high performance windows, prices fell.

While some thermal performance improvements may involve new materials as well as skills, for others, no new skills are required. For example, techniques to install double glazed windows and single glazed windows, or insulation of varying thicknesses, are largely the same. However, this is not always the case. High performance windows require special installation to reduce cold bridging. Double brick walls with larger cavities to accommodate thick insulation require unfamiliar construction such as the use of long wall ties. Currently, these techniques are not commonplace in Australia.

3.4 PAYBACK PERIODS/LIFE CYCLE COST

3.4.1 Previous studies

The purpose of most studies that assess the capital cost of thermal performance improvements is to determine their payback periods. The payback period is the time it takes (usually measured in years) for an energy saving measure to pay for itself as a result of the reduced energy costs it provides. While there may be debate about how much thermal performance improvements cost, numerous studies suggest they are eventually financially beneficial to the home-owner (Erlandson et al 1997, Gustafsson and Karlsson, 1997 cited in Joelsson & Gustavsson 2008). Krstic and Culo (2008) say that while energy efficient houses may cost more, their total life cycle costs are typically lower by 10-130%. However, Lippiatt and Helgeson (2008) note that claims of costs effectiveness are often based on anecdotal evidence rather than rigorous financial analysis.

Capital cost, payback periods and life cycle costs are all dependent on the level of energy efficiency that is being sought, and the cost of energy. Generally, improving the energy efficiency of a house (without altering its design), increases its cost. In addition, quantifying payback periods and lifecycle costs requires assumptions be made about the future cost of energy and the lifespan of a house. A number of Australian studies have been undertaken to determine the costs of improving the thermal performance standards of Australian housing. These show that higher energy standards increased construction costs with the additional cost being recovered over time because of the reduction in household expenditure on energy (Productivity Commission 2005). Prior to the introduction of thermal performance requirements in the Building Code of Australia in 2003, the consultants, Energy Efficient Strategies (2002) undertook a cost-benefit study of improving the thermal performance of a standard house of 2.5- 3 stars to 4 and 5 star thermal performance ratings. Using simulation software, thermal performance improvements were made to a large sample of typical housing in the Australian state of Victoria until the required level of thermal performance was achieved. The cost of each change was estimated. Cost and benefits were assessed over a 40-year period. Benefits included the savings from reduced energy used for heating and cooling as well as savings in plant costs needed to heat and/or cool the house. Achieving a 4-star rating increased the cost of a $170,000 new home by an average of 1.0 %. Achieving a 5-star rating increased the cost of the same home by an average of 1.9%. Benefits outweighed costs in each scenario assessed. However, the benefit to cost ratio was higher for 4-star than for 5-star houses. The low level of thermal performance of the base-case sample houses meant there were ample opportunities for low cost improvements, that is, there were plenty of 'low hanging fruit'.

The consultants, Energy Partners (2006) determined rule-of-thumb methods and their cost effectiveness for improving the thermal performance of timber-floored dwellings from 4 -5 stars. Using thermal simulation software, a range of techniques were applied individually to a sample of houses across a range of climate zones. Techniques were ranked in order of their cost effectiveness: the fewer dollars spent to achieve 5 stars, the more cost effective the measure. The study showed that achieving a 5 star rating for timber floor houses could be relatively easily and inexpensively achieved in all climates. However, the study had a number of shortcomings, some of which were acknowledged by the authors. The aim of the study was to compare the cost effectiveness of individual techniques, rather than optimizing several techniques to determine the highest star ratings for the lowest possible cost. Some of the techniques could complement each other so overall improvement in star rating could be greater than the aggregate of techniques applied individually. This means that the cost of achieving a certain increase in star rating is likely to be less if more than one technique is used concurrently. Moreover, the ranking of techniques may also change as a design becomes more thermally efficient. Furthermore, it is possible that the study overestimates the cost of some techniques. For example, all windows were changed from single to double-glazing, though this may not have been necessary to achieve a certain level of thermal performance.

Carrad et al (2008) looked at the costs and benefits of energy saving measures adopted in an Adelaide housing development. The houses had a thermal performance rating of 7.5 stars, considerably higher than the required minimum 5 star at that time. It was found that client preferences had a large bearing on whether a thermal performance rating could be achieved cost effectively.

In a Finnish study, Hasan et al (2007) increased the wall, floor and roof insulation of a model house incrementally, as well as the R-Value of windows. All scenarios tested showed that increasing the thermal performance of the house reduced its life cycle costs.

Florides et al (2002) studied various measures to lower a house's energy consumption in a cool-mild climate, and their relative cost effectiveness. Using a reference building, changes were made to the R-values of its envelope as a well as to orientation and building shape. They found that the installation of roof insulation and improved glazing were the most cost effective measures to reduce the heating and cooling loads of a house.

Song et al (2008) varied various elements of a standard apartment building in Korea to improve its energy efficiency. The cost effectiveness of each change was calculated. Two measures of cost effectiveness were calculated; the reduction in life cycle costs and the length of its payback period. The difference is that a relatively low cost option to increase energy efficiency may be paid back quickly but measures to substantially reduce energy use cost more and thus reduce life cycle costs but take considerably longer to payback. The cost effectiveness of each change was ranked in order for the two measures. The single change that was the most cost effective in terms of reducing life cycle costs was to substantially increase the wall insulation. The single change that was the most effective in terms of payback was to reduce window size.

Passive solar design relies on optimal orientation. It follows then that good orientation can play a role in minimizing the cost of achieving a certain level of thermal performance. However, in Australia, there is anecdotal evidence that project home-builders design houses to be as insensitive to orientation as possible. This allows the minimum thermal performance standard to be achieved irrespective of the way the house is orientated (Pitt and Sherry 2010). Nevertheless, Morrissey et al (2011) found that larger project houses were less likely to perform consistently through different orientations than smaller houses. This means that for some orientations additional cost would be incurred for the larger house to achieve a certain star rating. The study also found that all houses are less sensitive to orientation at higher levels of thermal performance.

Gieseler et al (2004) varied the wall, roof and floor insulation, as well as the U value of windows of a reference house to determine the most cost efficient option. The study also looked at the effect on energy use from varying the orientation of the house. There was a limit to the thickness of insulation and U-value of the windows above which it was no longer cost efficient. Any increases further reduced energy use but not to the extent that accrued savings would offset the initial capital cost. Varying the orientation showed that improvements in energy efficiency could be made without any increase in cost.

Rock (2009) notes slab insulation for slab-on-ground houses is justified both economically and thermally in a range of US climates. Perimeter insulation is beneficial in warm climates because it prevents heat gains through the slab edge and increases the heat losses to cooler soil below. However, there is a thickness limit beyond which it is no longer economical. In the US, homeowners will typically accept payback periods of up to 14 years.

Gaterell and McEvoy (2005) showed that the correlation between improved energy efficiency and lower life-cycle costs is valid up to a point. A very highly energy efficient house was not necessarily economically feasible over its life. However, a considerable increase in the cost of fuel, beyond what is predicted, may make the highly energy efficient housing more economically feasible as would extending the lifespan of the house thereby reducing the payback period. The Centre for International Economics (2010) undertook a study that concluded in most capital cities in Australia, a 5-star house rating was optimal. Beyond that point it was shown that the costs to achieve higher star ratings exceed the benefits (savings) they would provide over an assumed 40-year life. However, the study looked at a very limited number of thermal performance improvements and the study houses were not redesigned in any way to improve star rating.

Schneider & Hermelink (2006) claim that the PassivHaus standard is the best option for reducing the life cycle costs as well as life cycle emissions of houses. However, no empirical evidence was presented to support this claim. Parker (2009) says that there is a risk of over-investing in energy conservation measures to meet the PassivHaus standard. A study by Audenaert et al (2008) also questions the economic viability of building to this standard. They compared the payback periods of three house types: a Standard House, a Low Energy House and a PassivHaus, all built using traditional construction methods. The Standard house was built to meet the minimum level of thermal performance required by Belgian building codes. The Low Energy house was built to a higher thermal performance level with the aim of reducing energy use further. The PassivHaus was built to achieve the maximum heating requirement of 15 kWh/m^2 per annum. Based on the energy prices at the time, the payback periods to build the low energy house and passive houses compared to the standard house were 12.3 and 29.9 years respectively. The 'low energy' house was more economically viable than the PassivHaus for 45 years. Significant increases in energy prices were needed for the PassivHaus to become only marginally more economically viable than the low-energy house. In contrast, Mahdavi and Doppelbauer (2010) found that the additional cost of an apartment built to the PassivHaus standard over one built to a 'low energy' standard was paid back in 8-18 years.

Straube (2009) suggests that other building systems may be less costly and environmentally damaging than those needed to meet the PassivHaus standard. He notes that building to that standard can require energy conservation measures that are more expensive than installing photovoltaics to produce the same amount of energy saved. Others (Carrad 2008, Pitt and Sherry 2012) have found that this is the case in Australia, with the cost of PV having fallen dramatically in recent years. Pitt & Sherry (2012) determined thresholds in each Australian capital city climate zone beyond which further investment in thermal performance is less cost effective than photovoltaics to achieve a given level of reduction in electricity purchased from the grid. Therefore, building very thermally efficient houses rather than using renewable energy may produce more life cycle greenhouse gas emissions because of the high embodied emissions associated with the 'superinsulated'[5] envelope.

3.4.2 Shortcomings of payback period/lifecycle cost studies

Payback period/life cycle cost studies of energy efficiency measures for buildings typically look at single improvements, such as wall insulation, or compare single improvements such as wall versus ceiling insulation. Most previous studies establish an upper limit for an individual improvement beyond which any improvement is no longer cost effective, and compare it to other individual measures. The focus is not on finding one or a combination of options that provide a certain level of energy efficiency, or thermal performance, for the lowest possible capital cost.

The thermal performance measures that are used in studies are often based on anecdotes and rules-of-thumb. Some question this methodology. Williamson (1997) undertook a cost-benefit analysis of 4 common construction types located in a temperate Australian climate. The study showed that rules-of-thumb used for solar design to improve thermal performance cannot be relied upon and that there are a number of construction variations that fall within a suitable cost-benefit range.

Vaidya et al (2009) are critical of rule-of-thumb methods, suggesting they may not the most cost effective ways to improve a building's energy efficiency. Instead, they advocate a design approach that involves energy efficiency measures being considered interdependently that enables houses to be built with little increase in cost beyond a standard design. Any increase in design cost can be outweighed by lower total project

[5] A building which uses very high levels of insulation *i.e* well above normal practice

costs. This integrated approach in designing energy efficient residential buildings to reduce costs is supported by others (Harvey 2009). Using this approach Erlandson et al (1997) say that the costs of improving the thermal efficiency of house can be halved if it is considered at the design stage.

Another shortcoming of using rules-of-thumb measures is that their effectiveness may diminish if other elements that affect thermal performance are changed. For example, a rule-of-thumb to provide optimum window size for solar heat gain, and thus thermal performance improvement, may not be effective or even applicable if floor and ceiling insulation levels are altered. In the studies mentioned above, it was found that there are diminishing returns for changes to individual elements, sometimes to a point where they are no longer cost effective. However, it does not mean that the same level of thermal performance could not be achieved cost effectively. A number of changes can be made to a base design to improve its thermal performance. Changing one may affect the effectiveness of another. The cost-benefits of thermal performance changes may also vary as house size and shape changes, factors that are overlooked in most studies.

Cost-benefit studies assume a given amount energy will be saved from the implementation of the thermal performance improvement. However, the embodied energy of the improvement is rarely taken into consideration. This will partly offset any savings in energy and could affect the relative cost effectiveness of the thermal performance measure.

3.4.3 Predicted versus actual energy use

Studies of the cost-benefits of improving thermal performance calculate the payback period of energy saving measures. In doing so most assume that the predicted energy and actual energy used for space conditioning will be the same. Lowe and Oreszcyn (2008) note that in the UK there is little empirical evidence on the effect energy performance standards have on energy use. Where there is empirical evidence it has shown that measured energy savings deviate from predicted savings, and often negatively (Mills et al, 2006). Firth et al (2010) note that in cases where dwellings produce more CO_2 emissions than what is predicted from simulation models, it is usually much more. In contrast where dwelling produce fewer than predicted CO_2 emissions, it is usually only slightly less.

Sanders and Phillipson (2006) reviewed studies that compared the actual energy use with predicted energy use that resulted from increasing insulation levels of houses in the UK. Their review found that actual energy savings were on average about 50% less than what was predicted by energy simulation software, 15% of this could be attributed to the comfort factor, where occupants increase thermostat settings as thermal performance increases. The remainder of the discrepancy can be attributed to poor insulation installation, occupancy behaviour and infiltration rates varying from what is predicted. Inadequacies in simulation software were also noted as a possible contributing factor.

Karlsson et al (2007) and Wall (2006) in separate studies of low energy houses in Sweden also found a similar discrepancy between predicted and actual energy use. However, while the houses used more energy than what was predicted their overall energy usage was 60% less than the average house. Consequently, the goal of reducing energy consumption is realized, just not to the degree expected. However, Sunikka-Blank and Galvin (2012) found the opposite when the thermal performance of existing homes was improved. The results of a study of 3400 German homes showed that, on average, homes used 30% less heating energy than the calculated rating. The phenomenon increased with the calculated rating. They concluded that occupant behaviour may well be more significant than is generally assumed by policy-makers.

An Australian study (Williamson et al 2007) found little correlation between actual and predicted energy use for individual houses. However, the study only involved 30 houses and energy use was only measured over one year. It was also assumed that the extra energy used in winter and summer was for heating and cooling respectively. Phillipson and Sanders (2006) question whether such assumptions are reliable and accurate. They also note that a sample size of at least 100 houses is needed for a meaningful assessment of a thermal performance improvement that is predicted to reduce energy consumption by 25%.

While correlations can be weak between actual and predicted energy use for individual houses, studies have shown when the heating/cooling energy used in houses is aggregated the correlation strengthens. One of the studies reviewed by Phillipson and Sanders (2006) showed that for 59 houses the aggregate predicted energy use was very close to aggregate measured energy use, despite the correlation of individual houses being very weak. A comparison of the predicted versus actual energy savings of 24 public housing retrofit projects in the US showed a wide range of savings and variability of savings over time (Parker 2009). At some stages projects used more energy than predicted and at other times less. The range of energy savings from -12% to + 52% among individual projects over 6 years was reduced to a range of +16 to 25% when the projects were aggregated.

Schneiders and Hermelink (2006) compared measured energy use for space conditioning of 11 Passivhaus projects in Germany each with more than 100 dwellings, with predicted energy use of standard houses and found energy savings of over 80%. This was in the order predicted.

A study (Summerfield cited in Lowe and Oreszczyn 2008) involving an entire UK district showed that over about 35 years, the average gas consumption per house fell. Reductions in gas consumption coincided with successive changes in housing energy performance standards, though the author notes that a proportion of the reduction could have been due to other variables.

For the Leeds Metropolitan University study (2009) while the level of energy efficiency achieved was lower than predicted, it was still higher than that of houses built to the minimum required level. The report's authors note that reasons for the discrepancies between actual and predicted energy consumption need to be better understood, particularly if goals of zero carbon houses are to be achieved. To do so, would require monitoring of occupied houses, education and supervision of construction. In regards to the zero carbon target, Lomas (2009, p 190) notes that to achieve energy efficiency standards close to those required by legislation "a properly funded, politically supported system of building control is required".

Visual observations and testing during and after the construction process revealed that some of the discrepancies in energy performance were due to deficiencies in the building fabric. The thermal bridging through linear junctions was higher than predicted and the R values of the floors, walls and ceilings as constructed were lower than the simulation software calculated.

The results of the above studies indicate that payback periods, at least at the individual house level, would often be underestimated. The results of life-cycle cost studies of energy efficiency measures as well as the cost effectiveness of measures to improve thermal performance could therefore be misleading.

When complying with the energy efficiency provisions of the BCA using approved simulation software, a house design is rated in conditioned mode. That is, it is assumed the house is artificially heated and/or cooled. Kordjamshidi et al (2006) note that this penalizes passively designed houses in temperate climates; therefore free running ratings buildings should be rated differently from conditioned buildings.

There seems to be similar discrepancies between predicted and actual energy usage across a range of climates. However, predicting energy use is said to be more difficult for mild climates than severe climates (Soebarto and Williamson, 2001). In a study of Australian residential energy use (Energy Efficient Strategies 2008) it is noted that for a heating dominated climate, such as Tasmania's, occupancy patterns have a smaller effect on energy use than they do for more mild climates. Therefore, in estimating and forecasting the total energy use in the Australian residential sector, the study assumed that in Tasmania the actual heating (and very small amount of cooling) of new housing stock matched simulated energy use.

3.5 COSTS OF CO_2 EMISSIONS ABATEMENT IN THE BUILDING SECTOR

3.5.1 Abatement Opportunities

Previous studies of payback periods and the cost effectiveness of thermal performance measures were discussed. The focus of those studies was to determine the point at which the measures were economically worthwhile to the home-owner. Although there is a presumption that saving energy is environmentally worthwhile, those studies did not distinguish the fuel mix of the electricity used. To the householder, greenhouse gas emissions associated with the energy saved may be incidental; it is the payback period that is considered important. However, now the primary aim of housing energy efficiency regulations worldwide is to reduce greenhouse gas emissions, not to reduce the running costs of houses. The aim of the BCA energy efficiency provisions is to “reduce greenhouse gas emissions by using energy efficiently”. From an economic point of view it is in the interests of policy makers to set specific greenhouse gas (GHG) emissions reduction targets that are financially beneficial to the home-owner. In terms of CO_2-e mitigation policy, the monetization of environmental benefits is a powerful tool in highlighting priority actions (Mirasgedis et al 2004). Quantifying the GHG emissions that can be saved through thermal performance improvements, and the cost of the mitigation measures, provides a starting point to optimizing cost and greenhouse gas emissions.

It is claimed that the building sector offers large opportunities for low cost CO_2-e mitigation worldwide. Urge-Vorsatz and Novika (2008) reviewed studies of the potentials and costs of carbon dioxide mitigation in the world’s buildings. They found for both warm and cold climates, reducing the energy for space-conditioning, for example by installing insulation, provided the greatest savings in CO_2 emissions. It was estimated that by 2020 approximately 29% of the projected baseline emissions of the world’s buildings can be avoided cost effectively. 3% of baseline emissions could be avoided for less than US$20/tonne CO_2-e. Georgopoulou et al (2006) note that with the technology available today, the CO_2–e of the residential sector can be cut by 50%. However, not all measures are economically feasible to the home-owner over a house's life; assumptions about future inflation rates having a large bearing on whether or not that was the case.

With regards to the Australian building sector, the consultants McKinsey (2008) modelled the costs of CO_2 abatement measures over the full life of the measure. Negative cost measures were ones that paid for themselves through savings in energy bills they provided. It was found that by 2030, a total of 60 Mt of carbon reduction opportunities could be found, all at low or negative cost. However, whether low cost opportunities can be realized will depend on policy and behavioural change within the community (Pears 2004).

The total figures cited above for CO_2 abatement strategies are for the whole of the building sector. However, the actual cost effectiveness of measures is likely to vary between climates, and between buildings that differ in size and type (Mirasgedis et al 2004).

3.5.2 The Effect of Externalities

In economics, an externality is a cost or benefit not reflected in the capital cost of a product. Parties not involved in the manufacture or use of the product incur the external cost/benefit. For example, an external cost of a household's electricity use is the pollution caused by its production. This cost is borne by society. On the other hand, the carbon emissions saved through measures to reduce energy use is an external benefit to society. Compared to other developed countries, energy costs in Australia are low (DEH 2005) and fall well short of representing the actual cost to society.

For the price of electricity to reflect the external cost of carbon emissions associated with its production and use, then that cost needs to be internalised. The introduction of a carbon tax will internalize the costs of fossil fuel electricity production, but the extent to which this is the case will depend on the carbon price. The Stern Review (2006) estimated the social cost of carbon under Business-as-Usual (BAU) projections to be about US\$85/tCO_2. At a starting price of AUS\$23/tonne in 2012, the carbon price falls well short of Stern's estimate. However, there is a high degree of uncertainty attached to the external cost of carbon and therefore estimates vary widely.

Gaterell and McEvoy (2005) suggest that the inclusion of energy externalities would have a significant effect of the cost-effectiveness of energy efficiency measures. First, they calculated the Cost-benefit Ratio (CBR) of 4 single measures to improve the thermal performance of a reference house, where the CBR = cost of measure / cost of energy x amount of energy saved. Then, applying an external cost to the price of energy they showed how each measure became more cost-effective. However, the application of the external cost did not change their ranking order.

Similarly, Mirasgedis et al (2004) compared the economic costs/benefits of CO_2-e abatement polices in the Greek residential sector with and without applying an external cost to energy. They showed even without taking into account external costs that a significant reduction in CO_2-e could be made for little cost. However, once an external cost was applied, they became even more cost effective.

A study by the Centre for International Economics (2007) found that if the external cost of electricity production was reflected in its price then it was more likely that energy efficiency measures adopted by the Australian residential building sector would provide cost savings.

Other studies have compared the cost effectiveness of functionally equivalent building materials in reducing greenhouse gas emissions, with and without external costs being taken into account. Petersen and Solberg (2002) compared the cost effectiveness and life cycle greenhouse gas emissions of steel and timber glulam beams. They found that if the cost of carbon pollution was taken into account, the capital cost of the timber beams could be 1-6% more expensive than the steel beams but still more cost effective. The study noted that while the absolute costs of different building methods may vary, internalising external costs might change the relative economic standing of functionally equivalent building materials.

Sathre and Gustavsson (2009) studied the difference in carbon cost of using timber and concrete as the framing material for a 4-storey apartment building in Sweden. They found that when the external or social cost of carbon is included then wood improved its standing as the more economical building material. They made a number of assumptions that could affect the results. For example, they assume that there are no net CO_2 emissions from using wood waste as a biofuel because the emissions from combustion are balanced by carbon sequestered from subsequent forest growth. It is clear that boundary setting will strongly affect the comparative environmental performance of materials considered over their lifetimes.

Noller (2005) looked at the costs of embodied energy abatement measures for a commercial building in Australia and estimated that up to 30% abatement could be found.

A vast majority of studies into the cost effectiveness GHG abatement strategies in the building sector only consider the emissions savings that individual measures provide. A much smaller number of studies look at the cost effectiveness of different building systems in reducing GHG emissions. A study of GHG cost effectiveness of a building (Lippiatt and Helgeson 2008) took into account the embodied energy of the HVAC technology used to increase energy efficiency. The costs of various HVAC installations and the resulting operational energy costs were combined to provide a life cycle energy cost over a 25 year life. The life cycle carbon emissions (embodied emissions of the HVAC and the building, and the emissions associated with operational energy) of each option were calculated. A carbon efficiency ratio indicated the change in life-cycle cost per metric ton of carbon saved. The higher the ratio the greater the financial gain per ton of carbon saved. The study showed that ratios varied significantly depending on the HVAC system, its efficiency and the fuel type

3.5.3 Shortcomings of cost effectiveness studies

Studies of the residential sector that determine the cost effectiveness of energy efficiency measures, irrespective of whether external costs are included, overlook the embodied energy of the measure adopted. Compared to a reference house, the change in embodied energy to increase energy efficiency may be negligible, for example by using more efficient appliances or lighting. However, thermal performance improvements may result in a significant increase in embodied energy. The increase in embodied energy would depend on the level of thermal performance being sought and the methods used to achieve it. As described in Section 2.4.2 the embodied emissions can contribute significantly to life cycle emissions and in some cases outstrip savings in operational energy. If embodied emissions were considered, the cost effectiveness of some thermal performance measures would decrease and may also affect their ranking order. If an external cost is applied to the emissions associated with operational energy, it follows that an external cost should also be applied to the embodied emissions associated with the measure itself for the results to be meaningful. This too could decrease the cost effectiveness of thermal performance improvements.

3.6 EMBODIED ENERGY AND COST

Connaughton et al (2008) note that while there are numerous studies on capital costs and operational energy savings, little research exists that examines the embodied carbon and capital cost of buildings of a similar function and performance.

Previous input-output energy analyses have revealed an aggregate correlation between energy consumption (embodied energy) and economic output at the national level. However, little is known about the direct link between the energy cost of production and the selling prices of individual commodities (Liu et al 2008).

Langston and Langston (2008) studied 30 non-residential buildings of varying functions and sizes to determine whether there is a correlation between capital cost and embodied energy. The study found that for individual building elements, the correlation between embodied energy and cost was not strong. However, at a whole of building level a strong correlation existed. The authors concluded that capital cost can be used to reliably predict total embodied energy and they question whether the optimisation of energy and the optimisation of cost are mutually exclusive goals. Potential criticism that the relationship between embodied energy and cost is due to the nature of the embodied energy hybrid model used was countered by showing that a strong correlation still exists between embodied energy figures derived from process analysis, and cost. However, the study was of existing buildings, where presumably no effort was made to optimise cost and energy.

Noller (2005) examined the embodied energy abatement opportunities of a commercial building and showed that a 15% reduction of total embodied emissions was possible. The total building cost remained the same, showing that the correlation between cost and embodied energy is not strong in all cases. The findings also cast doubt on the suggestion by Lansgton and Langston (2008) that decisions made at a material level are unlikely to affect the total embodied of a building.

The impact of a carbon tax change on the cost-embodied energy relationship

A Davis Langdon study (2011) found that a carbon price would make very little difference to constructions costs for a range of building types. The analysis showed that the impact on the base supply cost of materials with high embodied carbon values, such as concrete and steel could be 5% and 2% respectively based on a starting price of $23 per tonne CO2-e. However, with the extent of industry assistance, the increase in costs for these carbon intensive materials is reduced to less than 0.5%. Furthermore, when the cost impact associated with all high carbon intensive materials is translated to overall build cost, the impact is far less. Even when industry assistance is completely removed the total increase in construction costs is estimated to be about 0.5%.

Nonetheless Commonwealth Treasury (2011) notes that explicitly pricing carbon ensures all companies and individuals either explicitly or implicitly factor into decisions the costs of greenhouse gas emissions. Companies and individuals do not need to make complex calculations about the emission intensity of particular goods, as the price of the goods will reflect that key information. Over time, as prices reflect the emission content of goods, producers and consumers will have an incentive to find ways to reduce emissions. For instance, electricity producers will look to reduce the use of emission-intensive fossil fuels to generate electricity and consumers will be encouraged to use less electricity.

3.7 CONCLUSION

This Chapter discussed the implications higher housing thermal performance standards might have on house design. In some countries it has been suggested that significant changes to the way houses are built will be necessary if reductions in emissions associated with house energy use are to be made. On the other hand, the experience within some countries, already having well developed construction systems, has shown that very little change in construction techniques is needed to build very thermally efficient houses.

A review of studies that examined the capital costs and payback periods of higher thermal performance standards was undertaken. Shortcomings of previous studies were discussed, including the relatively few design modifications that are made to base case houses and the issue of predicted versus actual energy use. However, a few studies have looked at the potentially beneficial impact of combining energy efficiency measures.

Finally, studies that showed the potential for low cost CO_2 –e abatement in the construction industry worldwide were reviewed. These studies did not take into account embodied energy that may be associated with improving energy efficiency. Although, for many measures such as improved lighting and mechanical services, this may be negligible.

It is apparent that very little research exists on the relationship between improving the thermal performance of houses, any consequential increase in embodied energy and the resulting cost of CO_2-e abatement. The following chapter outlines the research method used to address this shortcoming.

CHAPTER 4 – RESEARCH DESIGN

4.1 INTRODUCTION

It is evident from the literature that only a limited range of thermal performance measures is considered in studies of housing energy efficiency. Whether the effectiveness of these measures when combined with other improvements changes, as higher levels thermal performance are sought, is therefore unclear. It also follows then that little is known about optimizing cost and thermal performance, particularly for levels of thermal performance that exceed current standards.

Furthermore, while it is apparent that embodied energy makes a significant contribution to the life cycle energy of houses, it is not evident from the literature how it affects the cost effectiveness of thermal performance improvements in avoiding CO_2-e.

This chapter explains the methods used to address the following research hypothesis.

The cost effectiveness of reducing CO_2-e through improved thermal performance varies significantly depending on the materials and methods used.

In testing the hypothesis, there are a number of specific objectives. These include:

- To determine the most cost effective methods of improving the thermal performance of houses in cool-temperate climates;
- To determine if there is a point at which embodied emissions associated with achieving low energy houses results in an increase rather than a decrease in life cycle greenhouse gas emissions;
- To evaluate a range of solutions for achieving thermally efficient houses using currently available construction methods and materials in Australia.

By addressing the research hypothesis and the specific objectives listed above the research questions outlined in Section 1.3 can then be answered.

4.2 OVERVIEW OF RESEARCH METHOD

Below is a summary of the method used to test the research hypothesis.

- Reference Houses were selected to form the basis of the study;
- Using thermal simulation software, the thermal performance of the Reference Houses was improved by varying materials and construction methods so as to establish a range of designs for further evaluation;
- The cost of each design was estimated;
- The embodied energy associated with each design modification was calculated;
- The theoretical savings in CO_2 emissions associated with each thermal performance improvement was calculated;
- The embodied CO_2 emissions associated with each design was calculated; and
- The cost effectiveness of each thermal performance improvement in avoiding CO_2-emissions, embodied emissions and net emissions was calculated and ranked.

Each of these steps is discussed in detail below.

4.3 LOCATION AND SELECTION OF STUDY HOUSES

Location

Hobart, Tasmania was selected as the study location for several reasons. First, its climate (cool-temperate), and therefore the proportions of heating and cooling energy that make up total space-conditioning use of houses is very different to other Australian state/territory capital cities. In Tasmania, heating makes up almost all of total space-conditioning energy use, which means methods used to improve the thermal performance of houses are different to those located in more mild or hot climates. Second, the emissions intensity of electricity is much lower than it is in the mainland. And finally, most previous Australian studies on the thermal performance, embodied energy and cost/benefit of improving star ratings have involved houses in more populous mainland cities.

House type

As described in the previous chapter detached brick veneer housing is the most common housing type in Australia as well as in Tasmania. Also, in 2009-10, 88% of new dwellings built in Tasmania were single storey (ABS 2010). This is reflected in the standard designs offered by most project home builders.

Single-storey, brick veneer houses were therefore considered the most appropriate type to choose for a study investigating the implications of incrementally increasing the minimum thermal performance requirements of houses.

Reference houses

Three house plans were selected from high-profile local project home builders. Two of the house plans were amongst the builders' most popular designs and were chosen on that basis and because their size differed ($110m^2$ and $177m^2$, the latter being the Tasmanian average)[6]. A comparatively simple, rectangular house plan of $127m^2$ was also chosen. Each house is single-storey because this is the most typical house type in Tasmania. The purpose of selecting houses of different floor areas and floor plans, was to determine whether house size and shape affect the cost effectiveness of thermal performance improvements.

The floor plans of the houses are shown in figures 4.1, 4.2 and 4.3 below.

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[6] Note this is considerably smaller than the Australian average of $243m^2$.

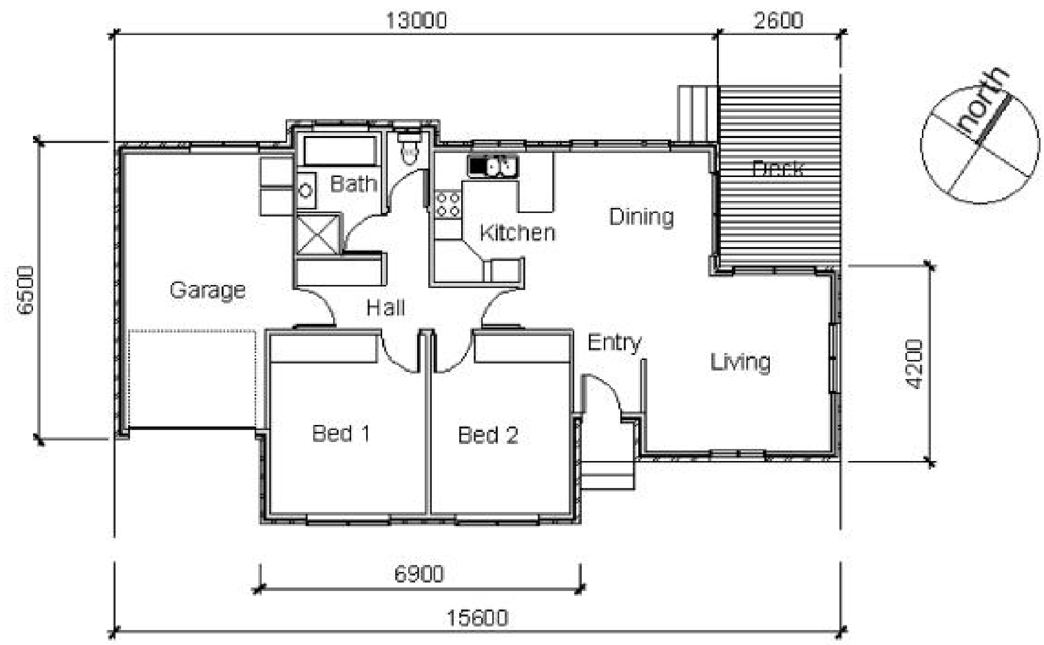


Figure 4.1 – Kingston House

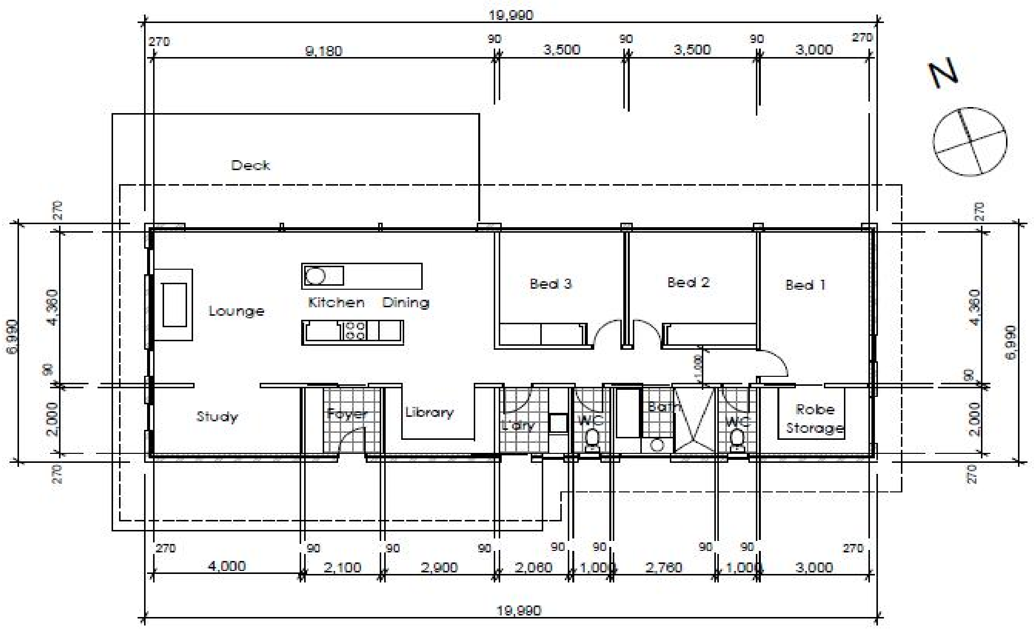


Figure 4.2 – Hickman House

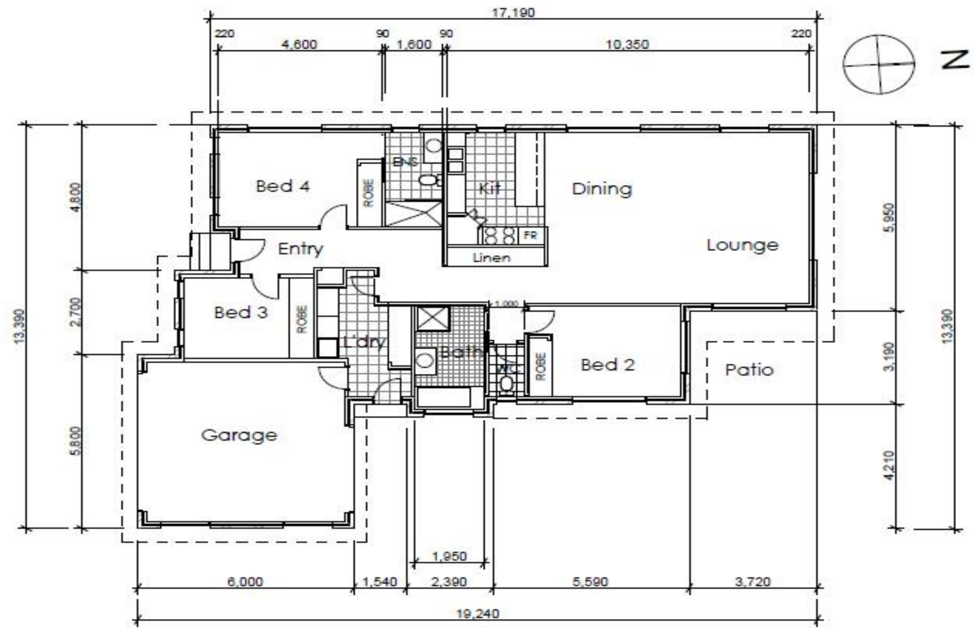


Figure 4.3 – Crimson House

Each house was designed to meet the 2009 minimum 4-star thermal performance requirement for Tasmania under the Deemed-to-Satisfy Provisions of the BCA. As such the building fabric of each above floor level is the same. The only difference in fabric is that Kingston House is designed as slab-on-ground. Table 4.1 shows the external building fabric of each house.

Table 4. 2 - Reference Houses' external building fabric

Element	Composition
External wall	Brick veneer (110mm brick, 35mm cavity, 90mm studs, 10mm plasterboard) Non-reflective building wrap. R1.5 fibreglass batts. Light coloured render.
Slab floor (Kingston)	100mm slab
Suspended timber floor (Crimson and Hickman)	Particleboard flooring on 90 x 35mm joists on bearers.
Floor coverings	Bedrooms and lounge/livingroom: Carpet and underlay Wet areas: tiles
Glazing	Single glazed, clear
Window and sliding door frames	Aluminium, medium colour
Eaves overhang	450mm
Roof	Dark Colorbond, reflective sarking
Ceiling	R3.5 Fibreglass batts. Non-vented downlights in living/dining and kitchens

Table 4.2– Reference Houses' total floor area, and glazing-to-floor area and conditioned floor area ratios

Reference House	Total Floor Area	Glazing to floor area ratio	Conditioned Floor Area (% of total floor area)
Kingston	110m^2	24%	65%
Crimson	177m^2	22%	62%
Hickman	127m^2	35%	64%

Table 4.2 above shows the glazing-to-floor area ratio and the conditioned floor area (CFA) as a percentage of Total Floor Area of each of the Reference Houses. Both are similar for each house. It is the space-conditioning energy requirement of the CFA that influences a house's thermal performance star rating. Having houses with very similar CFA to Total Floor Area ratio allows a meaningful comparison of cost/m^2 of thermal performance improvements of the houses to be undertaken.

The three selected study houses were used as Reference Houses. Each study house was also considered with the alternative flooring system (either slab-on-ground or suspended timber floor). Therefore, from the three selected houses, six Reference Houses are used for this study. The purpose of using Reference Houses with both suspended timber and slab-on-ground floors was to determine the degree to which the cost effectiveness of thermal performance improvements is influenced by floor type. Table 4.3 below shows the star ratings of the six Reference Houses.

Table 4.3 – Star Ratings of the Reference Houses

House	Timber floor	Slab-on ground
Kingston	3.8	4.3
Crimson	3.6	4.1
Hickman	3.8	4.4

4.4 THERMAL PERFORMANCE

4.4.1 Selection of simulation software

To quantify the thermal performance of the six Reference Houses, and improvements made to them, thermal simulation software was needed. Thermal simulation software is one method of demonstrating that a house design satisfies the energy efficiency performance requirements of the BCA. However, the BCA requires that the software be approved and accredited by federal and state governments and endorsed by the Association of Building Sustainability Assessors (ABSA).

Currently there are three accredited 2nd generation software assessment tools in Australia: AccuRate, BersPro and FirstRate 5. All three utilise the same simulation engine. For the purpose of this study, AccuRate V1.2.1.1, the latest version at the time of modeling was used to determine the thermal performance of the alternative house designs.

4.4.2 Software assumptions and limitations

In rating mode, the approved softwares use standardized, or default, occupancy profiles that define the periods of occupancy, occupant behaviour and preferred levels of thermal comfort. To achieve a thermal performance rating that complies with the relevant regulations, simulations of house designs must adopt these assumptions.

AccuRate assumes Living, Living/kitchen and Bedrooms zones are conditioned; that is, they are heated and cooled for certain periods of the day depending on climate. If other zones are to be conditioned (such as hallways or studies), then the house can be rated accordingly. It was assumed for this study only the Living, Living/kitchen and Bedrooms zones were conditioned, which was considered reasonable given the layout and size of the houses. AccuRate calculates the energy needed to heat or cool these zones if their temperature falls or rises outside the thermal comfort range during the assumed times of occupancy. Assumptions are also made about the heat gains from cooking appliances within the living/kitchen zone.

These assumptions are limitations of the software because occupancy patterns, behaviours and levels of thermal comfort will vary between households. This means that predicted energy needed for heating and cooling will not necessarily match actual energy usage. Criticisms of and suggestions for improving simulation software were described in section 2.2.5. Nevertheless, the star band rating assessed by the rating tool provides a theoretical comparison between design alternatives.

All 2nd generation software tools use an area correction factor when calculating the energy rating for a house design. The purpose of the factor is to account for smaller houses having a greater external surface area compared to the floor area than larger houses. The larger the surface area, the greater the heat flow through the building fabric. AccuRate's star ratings are based on the area corrected energy usage rather than the actual predicted energy usage. Energy usage is expressed as MJ/m^2 of conditioned floor area per annum. Heating and/or cooling appliance efficiency is not taken into account. Table 4.4 below shows the area adjusted star band score thresholds upon which ratings are based for BCA Climate Zone 7 (most of Tasmania).

Table 4.4 - Area adjusted star band score thresholds

AREA ADJUSTED STAR BAND SCORE THRESHOLDS									
1 star	2 star	3 star	4 star	5 star	6 star	7 star	8 star	9 star	10 star
723	498	354	262	202	155	113	71	31	0
MJ/m^2.annum									

4.5 IMPROVING THERMAL PERFORMANCE

4.5.1 Selecting an upper limit of thermal performance

Under the *National Strategy on Energy Efficiency*, Australian, state and territory governments established a National Buildings Framework. One aim of the framework is to "set increasingly strong minimum performance standards over time….with standards to be reviewed and increased regularly, for example every 3 years" (NSEE 2008).

On that basis it was decided that the thermal performance of the Reference Houses be increased to 7-8 stars, a standard that could reasonably be expected to be introduced within the next decade. A 7-8 star rating would also match the current minimum thermal performance for houses in other developed countries (Horne and Hayles 2008).

4.5.2 Construction methods and materials used to improve thermal performance

A range of construction methods and materials that improved thermal performance were identified and selected. These are shown in Tables 4.5, 4.6, and 4.7 below. They were modelled independently and in combination to achieve incremental increases in the star rating of the Kingston 4-star Reference Houses.

A wide range of thermal performance measures was chosen so that the resulting cost, embodied energy and improvement in star rating they provide could be compared and, as well, optimized. Table 4.6 shows that most of the individual insulation improvements actually consist of increasing insulation levels to at least two parts of the building envelope. The ratios of insulation to parts of the envelope are based on commonly used insulation ratios adopted to improve thermal performance.

The same thermal performance improvements were applied to the other Reference Houses as for the Kingston house. For each star band rating, from 4 to 8 stars, approximately 25 different modifications were modelled for the six Reference Houses, making a total of about 300 simulations.

Table 4.5 – Changes to window area, glazing and frame type

Code	Description of design modification	Code	Description of design modification
W1	Reduce windows in living/dining and bedrooms to 20% of wall area (approx 50% area reduction)	W7	Argon filled, doubled glazed windows (timber)
W2	Living/dining and bedroom window reduced (approx 30% area reduction)	W8	Triple glaze living/dining and bedroom windows (timber frame)
W3	Double glaze living/dining windows	W9	Reduce windows in living/dining room to 20%of wall area
W4	Double glaze living/dining and bedrooms windows	W10	Weatherstrip windows
W5	Timber windows	W11	Triple glaze living/dining room (timber frame)
W6	Thermally broken aluminum windows	W12	Thermally broken aluminium double glazed windows

Table 4.6 – Changes to insulation levels

Code	Description of design modification	Code	Description of design modification
R1	Floor insulation R3.0, wall insulation R2.5, Ceiling insulation R5.0	R13	Floor insulation R6.0, Wall insulation R2.5, Ceiling insulation R5.0
R2	Floor insulation R6.0, wall insulation R6.0, ceiling insulation R8.0	R14	Floor insulation R6.0, wall insulation R2.5, Ceiling insulation R5.0
R3	Floor insulation R3.0, wall insulation R6.0, ceiling insulation R8.0	C1	Slab with R1.0 under insulation, wall insulation R2.5, ceiling insulation 5.0
R4	Floor insulation R10, wall insulation R10, ceiling insulation R12	C2	Slab with R1.0 under insulation, wall insulation R6.0, ceiling insulation R8.0
R5	Floor insulation R5.0, wall insulation R6.0 ceiling insulation R8	C3	150mm slab with R3.0 under insulation, wall insulation R2.5, ceiling insulation R5.0
R6	Wall insulation R2.5	C4	Slab with R2.0 under insulation, wall insulation R6.0, ceiling insulation R8.0
R7	Wall insulation R2.5, Ceiling insulation R5.0	C5	150mm slab with R3.0 under insulation, wall insulation R10, ceiling insulation R12
R8	Floor insulation R1.5	C6	200mm slab with R3.0 under insulation, wall insulation R10, ceiling insulation R12.
R9	Wall insulation 6.0, ceiling insulation R8.0	C7	200mm slab with R3.0 under insulation, wall insulation R2.5, ceiling insulation R5.0
R10	Floor insulation R3.0, wall insulation R4.0, ceiling insulation R5.0	C8	200mm slab, Floor insulation R3.0, Wall insulation R8.0, Ceiling insulation R10.
R11	Floor insulation R8.0, wall insulation R8.0, ceiling insulation R10.0	C9	Slab R1.0

Table 4.7 –Other design changes

Code	Description of design modification	Code	Description of design modification
T1	Tiles in lieu of carpet in living/dining and bedrooms	L1	Take out downlights, make walls darker
T2	Tiles in lieu of carpet in living/dining room	F1	High span beams in lieu of 90 x 35mm joists

When using accredited software to assess thermal performance, ABSA lists National Simulation Protocols that must be followed. These include, but are not limited to, the following:

- Using the correct address and climate zone of the house to be assessed;
- Using only construction materials embedded in the software;
- Using insulation that is installed in accordance with the BCA;
- Zoning requirements and the circumstances under which zones are heated and cooled[7] and;
- Performing assessments within the published limitations of the approved software used.

As this study concerns compliance with current, and possible future, minimum thermal performance requirements all protocols were followed when undertaking assessments.

The level of thermal performance that the Reference Houses could reach without structural modifications was limited. Moderately improving the R-value of the building envelope meant that for some designs framing depths needed to be increased to accommodate thicker insulation. Floor and wall and roof framing sizes were increased, and the roof truss design modified accordingly. Increasing the R-value of the building envelope also meant

[7] Recent NatHERS modelling protocols suggest that for rating purposes hallways should be considered conditioned zones, although ultimately it is up to the discretion of the assessor. It was assumed for this study only the Living, Living/kitchen and Bedrooms zones were conditioned, which was considered reasonable given the layout and size of the houses.

that R-value of windows needed to be increased and/or consideration given to their size and location. Factors that governed changes to window size will be discussed in section 4.5.3.

Based on the data entered, AccuRate calculates a house's heat losses and heat gains to work out the theoretical energy needed for space conditioning. Before assigning a star rating to a design, AccuRate checks certain data that have been entered. The data check includes but is not limited to ensuring volumes have been calculated for nominated zones; that construction types for elements of zones, for example, floor, ceiling and walls, have been selected; and that window heights do not exceed wall heights. However, AccuRate does not determine whether installing a certain level of insulation is practical or even possible. For example, wall insulation of any thickness can be entered, irrespective of the stud thickness. Theoretically, a design could achieve a high star rating, but may be impossible or impractical to build.

For each of the modifications, consideration was given to the practicalities of using certain methods and/or materials to improve thermal performance. As well as practical limitations on the methods and materials used, there are also regulatory ones. These, and the factors that determined upper and lower limits for individual thermal performance improvements, are discussed below.

4.5.3 Practical considerations in selecting thermal performance improvements

Floor insulation

The practice of installing insulation beneath suspended timber floors is not widespread in Australia and there is no universally accepted method. The suspended timber floor of Reference Houses was not insulated because under the deemed-to-satisfy provisions of the BCA 2009 there was no requirement to do so if the sub-floor is enclosed. (Brick veneer houses with suspended timber floors have enclosed sub-floors).

Concerns have been expressed within the building industry about potential condensation and vermin problems associated with sub-floor insulation, as well as the insulation getting wet during installation. A report (Williamson and Beauchamp 2006) into the issues of insulating suspended timber floors found that these concerns were based mainly on anecdotal evidence. Nonetheless, they were considered when selecting suitable methods.

If the insulation is installed in conjunction with the platform floor; that is, the laying of insulation precedes the laying of the floor sheeting on the same day, the flooring should adequately protect the insulation from getting wet. Particleboard and plywood sheeting used for platform floors are both water resistant. Furthermore, both types are tongue and groove, which prevents water penetrating between side joins, and they are butt joined and glued over joists, preventing water penetration at this location. While laying the floor would have to be undertaken on a dry day, this would be the case even if insulation were not being used. Platform floors are laid before wall and roof framing commence whereas fitted floors are laid after the roof sheeting has been installed. Installing a fitted floor after the roofing would eliminate any possibility of the bulk insulation getting wet. However, platform floors are quicker and safer to install, and thus they are more common.

In the US, Lstiburek (2006) notes that in enclosed sub-floors where fiberglass insulation is installed between joists, condensation can form on the underside of the insulation and joists. This occurs in summer months when the underside of the insulation and joists is much colder than warm moist air that flows into the sub floor space. The warm, moist air condenses on the insulation and joists, whose surface temperature is below dew point. However, the surface moisture should readily dry out, leaving the timber and insulation uncompromised. To prevent condensation occurring, it is recommended that rigid polystyrene insulation be installed to beneath the joists to keep their underside warm.

The following methods were used to insulate suspended timber floors.

(i) 90mm x 35mm joists were used in the Reference Houses, which can accommodate an R2.5 rockwool batt. For floor insulation levels up to a maximum of R2.5 it was assumed that batts were installed between the floor joists supported on building wrap fixed between bearers (see Figure 4.4 below). As well as supporting the insulation, the building wrap provides some thermal resistance, would minimise the possibility of condensation occurring on underside of joists and insulation and prevent vermin entering the floor cavity.

Figure 4.4 – Insulation on building wrap

Source: Author (2010)

By installing insulation between joists, thermal bridging can occur through the joists compromising thermal performance. However, when AccuRate calculates thermal performance, the thermal bridging of framing members (the framing factor) is not taken into consideration. [8] To account for thermal bridging, two floor types can be modelled; the percentage of floor area comprising floor joists, and the remaining insulated floor area. However, as for insulated stud walls, this is not standard modelling practice and was not undertaken.

(ii) For R3.0 - R10 floor insulation, it was assumed that extruded rigid polystyrene insulation was fixed to the underside of joists from below floor level. This would eliminate thermal bridging through floor joists and the possibility of condensation as described above. However, it was recognized that installing R10 polystyrene would be difficult in a confined space. (The average height of sub-floor walls was assumed to be approximately 700mm). Therefore the upper limit of floor insulation was limited to R10.

(iii) An alternative option was to use deeper engineered joists, which can accommodate thicker insulation. It was assumed that 240mm deep hypsan joists spaced at 450mm centres, with a maximum single span of 4.6m, were used. One method for installing polystyrene insulation between the joists is shown in Figure 4.5 below.

[8] This has been recognised as a failing of Accurate. It is likely that future versions of the software will take the framing factor into account.

Figure 4.5 - Polystyrene insulation between engineered timber joists
Source: Author (2010)

For the suspended timber floor houses, the entire floor area of the house was insulated. Insulating the floor of WCs, laundries and bathrooms may have little if any affect on a house’s thermal performance star rating. However, for practical reasons it is likely that the entire floor would be insulated, with the result being that all rooms would be warmer, irrespective of star rating.

Irrespective of whether concerns about insulating sub-floors are warranted, an alternative method for insulating the floor area was considered for which those concerns would not apply. It has been suggested (Isaacs 2010), that insulating sub-floor walls is one such alternative. Insulating the sub-floor walls using polystyrene was simulated, however, this did not result in any thermal performance improvement. Therefore, in addition to the sub-floor walls, the ground surface of the sub-floor was also insulated and simulated, Again, there was no thermal performance improvement. This may be a shortcoming of AccuRate, as in theory this method should improve thermal performance and has been noted by others (Lees 2009). Since there was no improvement, it was disregarded as an option.

Under-slab insulation.

Provided under-slab polystyrene insulation has sufficient compressive strength there is no limit on the thickness that can be used. It was determined that the upper limit should be the R-value beyond which any increase provides little or no further thermal performance improvement. For structural reasons edge and thickening beams are not usually insulated. However, for the purposes of simulation it was assumed that entire slab area is insulated which, as for insulated walls and timber sub-floors, is standard practice in simulation.

Wall insulation

90 x 35mm studs were used in the walls of the reference houses, which can accommodate up to an R2.5 rockwall batt.

Where wall insulation exceeded R2.5, 150mm x 50mm wall studs were used to accommodate R4.0 rockwall insulation.

For insulation levels higher than R4.0, R4.0 batts were installed within the 150mm x 50mm studs and expanded polystyrene was fixed to the outside face of the stud wall. The maximum thickness of polystyrene used was dependent on the longest commercially available wall tie (to tie the external stud wall to the external leaf of brickwork). With the wall ties available, a maximum of R6.0 polystyrene could be used while ensuring a minimum 40mm cavity between the external leaf of brickwork and the outside face of the polystyrene. Figure 4.6 below depicts the method described.

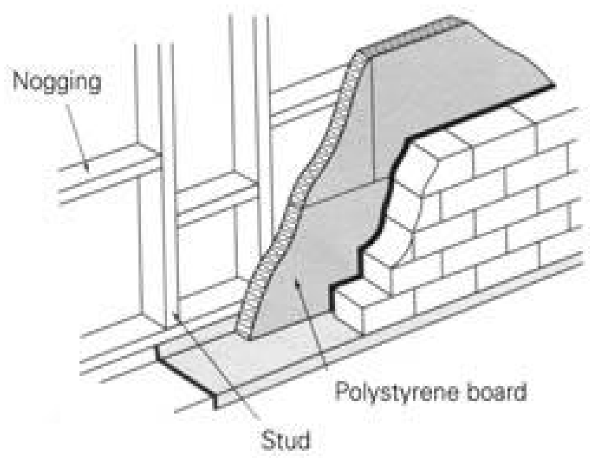


Figure 4.6- Polystyrene insulation in brick veneer cavity

Source: Building Science Corporation (2010)

Increasing the thermal resistance of the building enclosure reduces its drying potential and increases the relative humidity at wall surfaces, which can lead to condensation. Problems associated with the accumulation of moisture within a wall assembly can then occur, particularly if its internal and external surfaces are non-breathable. The likelihood of condensation occurring within a wall assembly will depend on a number of factors, including the climate in which the house is located. The condensation risks for each of the options considered is likely to be low as none involves both a non-breathable internal and external surface.

Ceiling insulation

Compressing insulation compromises its R-value. In a ceiling, compression can occur if there is insufficient space to accommodate the insulation or more than one layer of insulation is used.

Where roof insulation of R5.0 or higher was used, roof trusses required stepping up (heels) above the external walls to accommodate thicker insulation at this location. Figure 4.7 below shows the difference between a conventional truss design and one with a raised heel.

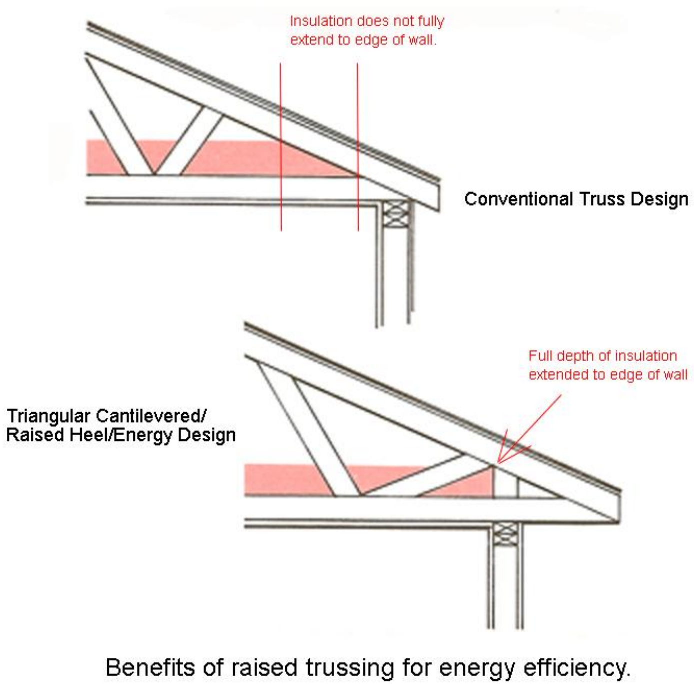


Figure 4.7 - Ceiling insulation in conventional truss and truss with raised heel

Source: Building Science Corporation (2010)

Compression can be minimised if the 2nd layer is installed perpendicular to the first, across the top of the bottom chords of the roof trusses, which provide support (Tumic 2009).The number of layers of insulation was therefore limited to two. R6.0 batts are the highest R-value ceiling batt available resulting in the upper limit of ceiling insulation having a total R-value of R12 (2 X R6.0 ceiling batts). However, given that the bottom chord of roof trusses is generally approximately 75mm, some compression is still likely to occur.

Window frames and glazing

Glazing area

Upper limit: The area of a Reference House's window was only increased if doing so improved thermal performance.

Lower limit: Regulations determined the extent to which window areas of the Reference Houses could be reduced. For habitable rooms the BCA requires a minimum window area of 10% of floor area. However, reducing all windows in habitable rooms to this size was not considered because such small windows are unlikely to be widely accepted in the market.

Research (Ghisi & Tinker, 2007) shows that for rooms no deeper than 8 m, window areas can be reduced to 20% of wall area without compromising views. Windows in bedrooms or living/dining rooms, or both, were reduced to this size as design modifications. For the Reference houses, this ratio easily satisfies the BCA minimum daylighting requirements. It was therefore used as a design modification for the Reference Houses.

In the bedrooms and living/dining rooms, south facing windows as well as windows assessed to be oversized were reduced in area or removed. For this design modification, the total reduction in glazing area of the windows in question was kept consistent for each Reference House, at approximately 30%. Again, the reduction was not to the extent that the BCA daylighting requirement could not be met. [9]

Glazing type

Four glazing types were modelled: (i) Single glazing, (ii) double glazing, (iii) triple glazing, and (iv) argon filled double-glazing.

Frame type

Three framing types were modelled: (i) aluminium, (ii) thermally broken aluminium and (iii) timber frames.

Triple glazing was only modelled within a timber frame because it was the only frame type readily available and for which a cost could be obtained.

[9] In terms of the provision of daylighting and view, the owners of the Kingston house indicated that glazing areas were more than adequate, and that the extent of glazing in the living/dining room and bedrooms actually presented practical problems. The layout of the living/dining room meant that furniture (couches) were placed in front of the lower panels of the floor-to-ceiling windows in the living/dining rooms (all external walls in this room have floor-to-ceiling windows), which still left ample unobstructed window area. Likewise in the bedrooms, the owners covered the lowest panels of fixed glass of the floor-to-ceiling windows to increase privacy.

Shading

Each Reference house had 450mm wide eaves. Because this is the standard eaves width for brick veneer houses in Tasmania it was not changed.

Where window/sliding door sizes were reduced, this involved, in some cases, reducing both their height (but keeping head height the same) and width. The height of windows was not decreased to the point where loss of solar gain diminished thermal performance.

While overshadowing of trees, external screens and adjacent buildings may influence internal temperatures, they were not modelled as they are site specific and therefore not relevant to a generalised assessment of Reference House envelope modifications.

Thermal mass

Utilising and/or increasing existing thermal mass, or introducing thermal mass were identified as ways to improve the thermal performance of the Reference Houses.

The living/dining rooms and bedrooms of each Reference House were carpeted. For the concrete slab houses, a dark tiled flooring replaced carpet to utilize the slab's thermal mass. In addition, various slab thickness were modelled. It was determined that the maximum slab thickness modelled would be that beyond which any further increase in thickness provided little or no thermal performance improvement.

The houses were modelled as conventional brick veneer; reverse brick veneer was not considered, as this is not the norm in Tasmania.

External wall colour and downlights

External wall colour and internal downlights were identified as factors influencing thermal performance. The Reference Houses had light wall colours. Dark wall colours were modelled in addition to light colours.

The Reference Houses had vented downlights in the living/dining rooms. The houses were modelled without them since they increase infiltration losses.

Insulating between zones

It has been suggested that insulating between zones is as an economical way to improve thermal performance (Isaacs 2010). However, modelling of the houses where walls between conditioned and non-conditioned zones were insulated showed a negligible improvement in star rating. Therefore this option was disregarded.

Orientation

The results are based on the houses being orientated for optimal thermal performance as indicated in figure 4.1, 4.2 and 4.3 in section 4.3. The extent to which orientation affects thermal performance (star rating) is examined in section 5.7– Sensitivity Analysis in Chapter 5.

4.6 COSTS

4.6.1 Construction cost of reference houses

The construction costs of the Reference Houses were needed to determine the percentage increase in construction cost that resulted from each thermal performance improvement. The Reference Houses' construction costs on flat land were based on the builders' cost estimates, which included profit and preliminaries. It was assumed that for a given design on flat land, the cost of constructing a slab-on-ground and suspended timber floor was the same. This enabled a simple cost comparison of thermal performance improvements of the two floor types. Table 4.8 shows the construction cost of the reference houses.

Table 4.8 – Construction Cost of Reference Houses

Reference House	Construction cost
Kingston	\$150,000 (\$1363/m^2)
Crimson	\$238,950 (\$1350/m^2)
Hickman	\$172,720 (\$1360/m^2)

In reality, differences in actual and relative costs between the floor types varied between builders. Of the two builders who supplied house plans, one advised that on a flat site it is cheaper for them to construct a suspended timber floor than a slab, whereas for the other builder, the opposite was the case. However, for both builders, the difference in cost between the floor types on a flat site is marginal; less than 0.5 % of total construction cost.

4.6.2 Calculating costs of thermal performance improvements

A quantity surveyor provided cost estimates for all building elements of the Reference Houses. The costs of changes to the building fabric were based on the quantity surveyor's unit rates where provided. There were thermal performance improvements made for which the quantity surveyor did not provide estimates. For most of these improvements estimates were obtained from Rawlinsons Cost Guide (2009). For example, the cost of using thicker stud walls, engineered joists and thicker insulation. However the remainder of improvements involved materials methods that were atypical and for which Rawlinson Cost Guide does not provide costs. The costs of materials for these improvements were obtained from local suppliers where available. The labour costs associated with the improvements were based on estimates from local builders familiar with the techniques described.

Following is a description of how each thermal performance improvement was estimated.

Floor insulation

(i) To estimate the cost of installing insulation between the joists, it was assumed that breathable building wrap was fixed across the top of bearers before laying the floor joists, as previously described. The building wrap supports insulation that is placed between the joists prior to fixing the platform floor.

(ii) Where one layer of polystyrene insulation was installed to the underside of floor joists it was assumed to be screw-fixed. If additional layers of polystyrene were used, it was assumed they were glue-fixed to the underlying layer(s). In no wind areas, which would be the case in the sub-floor, mechanical fixings are not required. Although not assessed by AccuRate, it was assumed that alternate layers were glued perpendicular to each other to reduce air infiltration through joints. Labour costs were increased proportionally with the number of layers installed.

Expanded polystyrene with a low compressive strength was used. The same R-value can be achieved with thinner, extruded polystyrene but it is more expensive.

(ii) Where deeper engineered joists were used it was assumed that polystyrene insulation was installed, supported between flanges of adjacent beams (see figure 4.4). Another option that was estimated, assumed bulk insulation supported on fibrecement sheets that lay between flanges of adjacent beams.

Deeper engineered beams span further than the joists of the Reference Houses. Therefore, fewer bearers, brick piers and pad footings are needed. This was taken into account in the cost estimates.

Under slab insulation

Expanded polystyrene with adequate compressive strength (medium grade) was used. Estimates were based on what was simulated; the entire slab area excluding garages.

Wall insulation

(i) The 90 x 35mm wall studs of the reference houses could accommodate R2.5 insulation. The increase in construction cost from using R2.5 is the difference in cost between R2.5 and the R1.5 insulation used in the Reference houses.

(ii) For insulation levels higher than R4.0, R4.0 batts were installed within 150mm x 50mm pine studs and polystyrene was fixed to the outside face of the stud wall. As for sub-floor insulation, where one layer was installed it was assumed to be screw fixed, with additional layers being glue fixed. Polystyrene increased the distance between the stud and brick wall requiring longer wall ties. Using polystyrene makes building wrap unnecessary and this was taken into account in cost estimates.

Significantly increasing the total thickness of brick veneer external walls has implications for internal finishing around windows. Larger internal reveals, or windows fitted with wider jambs, or both, would be needed. This has not been taken into account in estimating costs of thicker walls.

If 150 x 50mm studs were used, the stud spacing could increase to 600mm centres, resulting in fewer studs being needed, reducing labour costs. Even framing at 450mm centres could be made more efficient. Lstiburek (2005) points out that current framing practices use excessive quantities of timber, leading to unnecessarily high labour and material costs. If roof framing members, walls studs, and floor framing members lined up to transfer loads directly to the footings, far less timber would be needed. Double wall plates, double studs around wall openings, and the jack studs beneath become redundant. Figure 4.8 below shows how timber can be minimized by more efficient framing techniques.

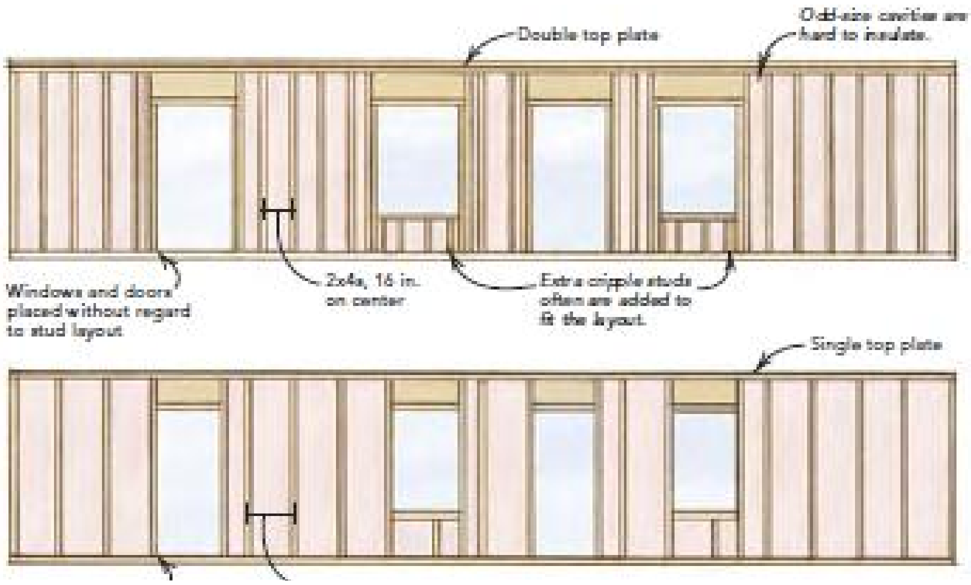


Figure 4.8 – A comparison of traditional (top picture) versus more efficient framing techniques (bottom picture)

Source: Building Science Corporation (2010)

However, for all but one design modification, it was assumed that increasing stud size had no influence on framing practice. One design modification that used a more efficient framing method was estimated to provide a cost comparison with the designs that used traditional framing methods.

It was recognized that increasing the thickness of external walls reduces the floor area. If the original floor areas were to be maintained, all elements of the building envelope would have to be increased slightly, however this was not taken into account.

Ceiling insulation

Where a heel was required in roof trusses to accommodate thicker insulation it was assumed to have a negligible affect on the trusses' cost. The cost of the additional course/s of brickwork needed to match the height of the heel has been taken into account.

Windows – frames and glazing

Where window areas were decreased, the nett external wall area (total wall area minus window area) increases by the same amount. This was taken into account when estimating the cost of reducing window areas.

Changes in the external wall cost were based on an estimated elemental rate ($/m2), which included brickwork, reflective foil insulation, the stud frame, insulation, plasterboard and painting. In some cases, window widths were decreased to a size that would have permitted a shorter timber lintel. The cost of smaller lintels was not estimated as it was considered negligible. There is no brickwork above window/external door openings of the Reference Houses as window/external door heads are the same height as the eaves.

Changing window frames from aluminium to timber in a garage or WC would have little, if any, influence on a house's star rating. However, for aesthetic reasons it is very likely only one frame type would be used for all windows in the house. For this reason, changing window frames from aluminium to timber involved all windows and was costed on that basis. (The exception to this might be where an aluminum window is used in a bathroom but timber windows are used elsewhere).

Double-glazing: the increase in cost was the difference between single- and double-glazing.

Triple-glazing: In Australia, there is very little demand for triple glazing; consequently there are very few suppliers. There were no locally based triple-glazed window manufacturers. For the purpose of costing, estimates were obtained from a manufacturer in Victoria who supplies the Tasmanian market. Estimates for triple-glazing were based on the windows having timber frames.

External wall colours and downlights

It was assumed that changing wall colour does not affect cost.

Where vented downlights have been removed it was assumed that alternative lighting is the same cost; that is, removing recessed downlights is a no-cost change. There are methods to keep downlights without compromising thermal performance, such as setting them in a bulkhead, or installing them on a track or a rose, which do not result in ceiling penetrations.

Thermal mass

Rawlinsons Cost Guide 2010 (the most current at the time calculations were being undertaken) was used to estimate the cost of a thicker slab and substituting the carpet for ceramic floor tiles.

Weatherstripping

It was assumed weatherstripping involved sealing around the external perimeter of windows with a proprietary material. For this, an allowance of $2.00/lineal metre has been made, including labour and materials.

4.6.3 Reliability of cost estimates

As for any element of a house, the cost of a thermal performance improvement is likely to vary between builders. Actual costs will depend on a number of factors including the builder's workload, the location of site, the size of the company (project home builders can reduce materials costs by bulk buying), and supplier and sub-contractor relationships. Estimates provided by cost guides, such as Rawlinsons, as well as by quantity surveyors are indicative only and tend to be conservative.

4.6.4 Cost of compliance in the future

The various shortcomings of simulation software have been discussed previously, and some or all of these may be overcome in the future. Potentially, the star rating that a particular design currently achieves could change if rated with modified software. This in turn may affect the cost of compliance. Furthermore, to achieve the BCA's stated objective of reducing houses' greenhouse gas emissions, in the future the assessed criteria could be broadened beyond to include, for example, all fixed appliances and/or account for the use on-site renewable energy. Changes in the mix of renewable and non-renewable energy in Australia and in Tasmania in particular could also affect the assessment. Again, these would influence the cost of compliance. Finally, the cost of some products and technologies that relate to improving thermal performance may reduce in the future, particularly if their uptake increases and manufacturing efficiencies are improved. This research, however, is based on what is known currently, and the current cost of compliance, not on what may or may not occur in the future.

4.7 EMBODIED ENERGY

4.7.1 Method for calculating embodied energy

An Input-Output Based Hybrid Analysis was used to calculate embodied energy. This method and its advantages over other methods were described in Chapter 2 (section 2.4.1). Table 4.9 below shows the energy intensity figures used for common building materials.

Table 4.9 – Energy Intensity of building materials.

Building material	Unit	Total Energy Intensity (GJ)
Aluminium	tonne	252.605
Bricks	m^2	0.560
Carpet-wool	m^2	0.741
Carpet-nylon	m^2	0.683
Cement	tonne	16.007
Clear float glass (4mm)	m^2	1.728
Concrete 15 MPa	m^3	3.626
Concrete 20 MPa	m^3	4.004
Concrete 25MPa	m^3	4.573
Concrete 32 MPa	m^3	5.343
Fibre cement sheet (4.5mm)	m^2	0.235
Fibre cement sheet (6mm)	m^2	0.288
Fibreglass insulation R2.5	m^2	0.217
Rockwall insulation R2.5	m^2	0.1628
Expanded polystyrene insulation (50mm)	m^2	0.361
Plasterboard (10mm)	m^2	0.207
Plasterboard (13mm)	m^2	0.232
Plastic	m^2	163.367
Aluminium reflective foil	m^2	0.137
Sand	m^3	0.617
Screenings	m^3	0.691
Colourbond	m^2	0.588
Steel, structural	tonne	85.463
Tiles, ceramic	m^2	0.293
Timber, hardwood	m^3	21.326
Timber, softwood	m^3	10.925
Toughened glass (6mm)	m^2	3.657
Water based paint	m^2	0.096
UPVC pipe 100mm	m	0.266

Source: Crawford, R.

4.7.2 Calculating embodied energy of Reference Houses

The initial embodied energy (that is, the embodied energy excluding recurrent embodied energy) of the Reference Houses was needed to determine the percentage increase in initial embodied energy that resulted from each thermal performance improvement. The embodied energy calculated included the houses' substructure, building envelope and floor coverings; that is, elements that can change and improve thermal performance. Fixtures, Prime Cost items, landscaping, decks, and so on were not included in the calculations.

The material quantities of the Reference Houses obtained from a quantity surveyor include wastage; a standard quantity surveying practice. Therefore, a separate material wastage factor was not used in calculating the total energy intensity of the Reference Houses. Most of the thermal performance improvements involve increasing insulation levels (and frame sizes to accommodate the extra insulation where necessary), decreasing window size, and changing glazing type. These changes would not result in maintenance requirements over and above what would otherwise be required therefore their recurrent embodied energy was not included.

A research objective was to determine the relationship between incremental increases in thermal performance, capital cost and embodied energy of brick veneer houses with different floor plans and areas. Having the same building fabric meant that for Reference Houses with the same floor type, differences in initial embodied energy can be wholly attributed to differences in house size and shape, and not different materials. This enables meaningful comparisons to be made of the relative changes in embodied energy of the Reference Houses as their thermal performance improves.

The following assumptions were made in calculating the initial embodied energy of the reference houses:

Substructure

A given substructure's embodied energy will vary depending on the slope and soil type of the site. For example, the edge and stiffening beams of a slab on a highly reactive clay site (site Class H) will be deeper and require heavier reinforcement than a slab on a stable sandy or rock site (site Class A). Consequently, it will have a higher initial embodied energy. Similarly, the depth and reinforcement of a strip footing supporting external walls of a brick veneer house with a suspended timber floor will vary according to the site classification. The depth of the concrete pads supporting brick piers may also vary depending on the soil type.

On a sloping site, to build a brick veneer house on a concrete slab can require constructing a reinforced wall to retain fill material. Because of the additional labour and materials needed the initial embodied energy would be higher than that of a slab on flat ground. For a brick veneer house with suspended timber floor, a steeper slope will result in additional sub floor walls, higher piers and perhaps stepped footings, resulting in a higher initial embodied energy (and cost).

It was assumed that the six Reference Houses have been constructed on flat land with the same soil type. For the slab-on-ground designs, therefore, the dimensions of the edge and thickening beams were the same and, for the suspended timber floor designs, the strip footings, depth of concrete pads and the height of subfloor walls and brick piers were the same. Two of the Reference Houses have attached garages. In the case of the suspended timber floor houses it is assumed that the garage slabs are slab-on-ground, that is, they have not been constructed on compacted and retained fill.

Consequently, the substructure of the slab-on-ground designs and the suspended timber designs for each house was the same, and it was assumed that the slope and soil type was consistent for each one.

For the Kingston Reference Houses (suspended timber floor and slab-on-ground) the energy intensities of elements that make up the substructure were calculated. For the slab-on-ground house this included the sand and fill material, the polyethylene membrane, concrete (slab, and edge and thickening beams) and steel reinforcement (trench and slab mesh). For the suspended timber floor house this included concrete (strip and pad footings), steel reinforcement in strip footings, brick piers, timber joists and bearers, and particleboard flooring. The aggregate of the individual components for both floor types was divided by the floor area to give an energy intensity/m^2. Using these figures, the total energy intensity of the floors for the other Reference Houses was calculated. For the suspended timber floor houses the energy intensity of the sub-floor walls was calculated separately for each house to take into account the different a wall-to-floor area ratios. The energy intensity of the suspended timber floor houses' garage slab was also calculated separately.

Roof

The roof pitch and roof framing method for each house was assumed to be identical; that is, batten size and spacing, truss spacing and configuration, truss member sizes, and the number of fixings per truss, were all the same.

The energy intensity of the roof framing's individual components was calculated for the Kingston Reference House. The aggregate of these individual components was divided by the roof area to give an energy intensity per m^2 (in the horizontal plane) for roof framing. Using this figure, the total energy intensity of the roof framing of the other houses was calculated.

Windows and doors

The mass of the aluminium windows and doors for each Reference House was obtained from Dowell Windows.

It was assumed that 4mm toughened glass has been used in all windows/doors of the reference houses.

4.7.3 Assumptions made about materials' quantities

Where improving the thermal performance of the Reference Houses involved adding materials not used in the Reference Houses, an allowance for on-site wastage has been made where applicable.

Roofs

Modifying the roof trusses to include a heel above external walls would result in a slight increase in the total volume of timber. This was considered negligible and was not taken into account. The height of the external brick wall needed to be increased to match the height of the heel. The extra brickwork was taken into account in the embodied energy calculations.

External walls

Where window width decreased, a shorter timber lintel, and in some cases one with smaller cross sectional area, could have been used. However, the reduction in total timber volume was considered negligible and was not taken into account.

Where larger studs were used to accommodate thicker insulation the resulting increase in embodied energy was calculated.

Windows/doors

Where aluminium windows/door areas were changed, their mass was calculated using kg/m^2 of the Reference Houses' windows/doors of the same style.

Energy intensity calculations of timber window/door frames as well the windows and doors themselves were based on the total volume of timber.

It was assumed that where window sizes changed that the glazing type, 4mm toughened glass, remained unchanged. However, depending on the size and location of the window, 3mm toughened glass could have been used in lieu of 4mm toughened glass, or toughened glass may not have been required at all.

Where windows were changed to triple glazing, it was assumed that the middle pane, being encased by 4mm toughened glass, could be 3mm float glass

Floor insulation

Changes in the embodied energy of floor insulation were based on the energy intensity figures in Table 4.9.

Wall insulation

Changes in the embodied energy of wall insulation were based on the energy intensity figures in Table 4.9.

Lights and wall colours

It was assumed that there was no change in embodied energy resulting from changing lighting type or colours.

4.8 CALCULATING HEATING/COOLING CO_2 EMISSIONS

4.8.1 Method

In Tasmania heating accounts for about 98% of space-conditioning energy[10]. It was therefore assumed that the total space-conditioning requirement was for heating, as the cooling load is negligible.

It was also assumed that electric heating appliances with 100% efficiency were used.[11] That is, the heater's output equals its input. However, sensitivity analysis was undertaken (see section 5.7) using gas and more efficient electric heaters (heat pumps).

The space heating energy is converted into heating CO_2-e since the objective of the BCA energy efficiency provisions is to reduce greenhouse gas emissions, and one purpose of this study is to examine its cost effectiveness.

The CO_2-e associated with space conditioning energy usage was calculated for each of the design modifications. The theoretical energy usage (MJ/m^2) for space heating and cooling is calculated by AccuRate. That figure was multiplied by the conditioned floor area to provide a total MJ/annum figure. As previously mentioned, AccuRate calculates the heating and cooling energy requirement of a particular design as well as an area adjusted

[10] This is based on AccuRate calculations which split total space-conditioning load into annual heating and cooling requirement

[11] Electric resistance heaters are typically around 100% efficient

heating and cooling energy requirement upon which the star rating is based. The unadjusted figure was used because for the purpose of this research it is the energy required for space conditioning, irrespective of house size that is assessed.

The total MJ per annum figure was converted into kWh (dividing by 3.6). This was converted into $C0_2$-e by multiplying it by the emissions factor, 0.12 kg CO_2-e /kWh, for electricity from the grid in Tasmania for 2007-2008.[12] The resulting figure is the annual CO_2-e from heating and cooling using electricity. It was assumed that the emissions intensity of electricity remains constant over the modelling period. In reality it is likely to fluctuate, but it would be difficult to make reliable annual forecasts of the emission intensity of Tasmanian electricity for the next 25 years. Treasury does provide forecasts of the emissions intensity of the eastern states National Electricity Market (NEM) of which Tasmania is a part (via Basslink). However they are NEM averages and are not directly applicable to Tasmania. While the electricity intensity of the NEM has been falling and is predicted to keep falling in the future (see figure 4.9 below), it does not necessarily follow that the emissions intensity of Tasmanian grid purchased electricity will also fall.

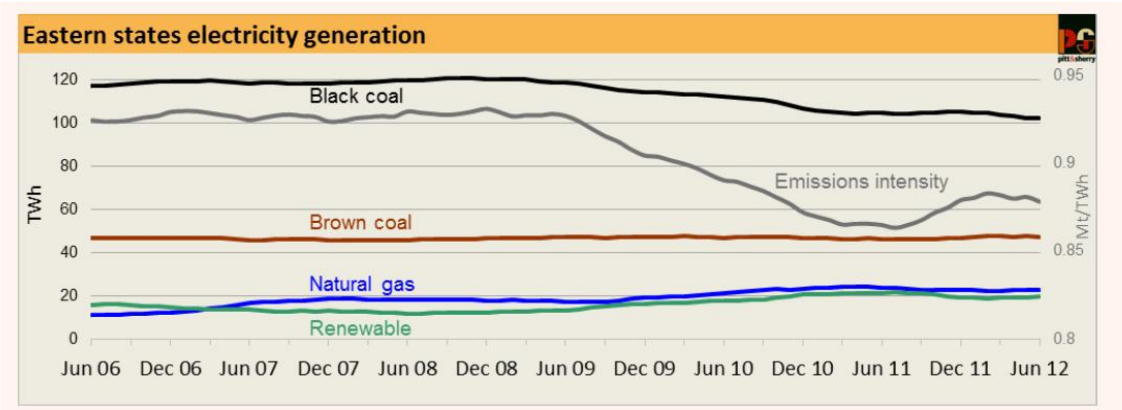


Figure 4.9 – NEM electricity generation and emissions intensity

Source: Pitt and Sherry (2012)

12 The period 2007-2008 was a period of average rainfall in Tasmania. The emissions factor is higher in dry years when electricity is imported via the Basslink cable linking Tasmania to the Australian mainland, and lower in wetter than average years.

4.8.2 Reliability of data

The state/territory based emissions factor calculates an average emissions factor for all electricity consumed from the grid in a particular state/territory. The emissions factor is based on each electricity generator's relative level of supply to the grid. The reason for this approach is that within an electricity grid it is impossible to physically trace the actual source of electricity received by each consumer. For example, in Tasmania, consumers at a particular time may be receiving electricity that is generated from hydro power stations, or electricity generated from Basslink imports (coal fired power stations), or a mixture of the two.

This study assumes that energy used to heat and cool houses is grid-supplied electricity. In reality, this may not be the case. A house may use gas, a wood heater or combination of sources. Alternatively, it may be partly or totally reliant on electricity generated from on-site renewable sources such as photovoltaics. Moreover, it has been assumed that the predicted energy needed for space-conditioning matches the actual energy used. This is not always the case as explained in section 2.2.5

4.9 CALCULATING EMBODIED CO_2 EMISSIONS

Most studies that have looked at embodied or operational energy, or both, as part of life-cycle energy, have not converted energy into CO_2-e. The distinction between embodied emissions and embodied energy is an important one. If energy is generated from renewable resources, which is likely to become more common, the amount of energy used becomes less relevant from an environmental perspective. Importantly, the objective of BCA energy efficiency provisions is to reduce greenhouse gas emissions.

Several recent studies (Noller 2005, Pullen 2007) have converted embodied energy into embodied CO_2-e. Both studies used an Input-Output model to calculate the embodied emissions associated with buildings. In another study, Treloar (2000) used an average figure of 60kg CO_2-e per GJ of energy. Using an IO method, both Noller and Pullen obtained CO_2-e figures for individual building materials which on average were slightly higher than Treloar's average figure. The higher average figure of 65kg CO_2-e per GJ of energy was used for this study. The total initial embodied energy figure of the Reference Houses and each design obtained using IOBHA was converted to GJ and multiplied by 65kg to give a total embodied emissions figure. The calculations are included in Appendix E.

Although the emissions intensity of grid generated electricity is significantly lower in Tasmania than it is on the mainland, using the national average figure of 65kg CO_2-e per GJ for embodied emissions was considered appropriate because it was reasonably assumed that the materials used to improve the thermal performance of the Reference Houses e.g. improved glazing, window frames, and insulation, were manufactured on the mainland. In any case the method used to calculate embodied energy captures both direct and indirect energy used in the manufacture of materials. The indirect energy component includes the total *national* energy intensity of the relevant sector of economy to which the material belongs. Furthermore, depending on the material, the indirect energy can be much more than half of its total embodied energy.

4.10 COST EFFECTIVENESS IN REDUCING CO_2-e EMISSIONS

4.10.1 Method for calculating cost effectiveness

The cost effectiveness of a thermal performance improvement can be represented by the ratio of the cost of the thermal performance improvement ($) to the resulting theoretical savings in CO_2 emissions, that is, $ divided by CO_2-e saved. The lower the ratio, the more cost effective the measure.

Three measures of cost effectiveness for each thermal performance improvement (for each house in each star band) were calculated. They were:

1) The cost effectiveness in reducing the CO_2-e associated with the energy used for space heating and cooling.

2) The cost effectiveness in minimising the associated increase in embodied CO2-e.
3) The cost effectiveness in saving life cycle emissions (the reduction in space-conditioning emissions added to the change in embodied emissions).

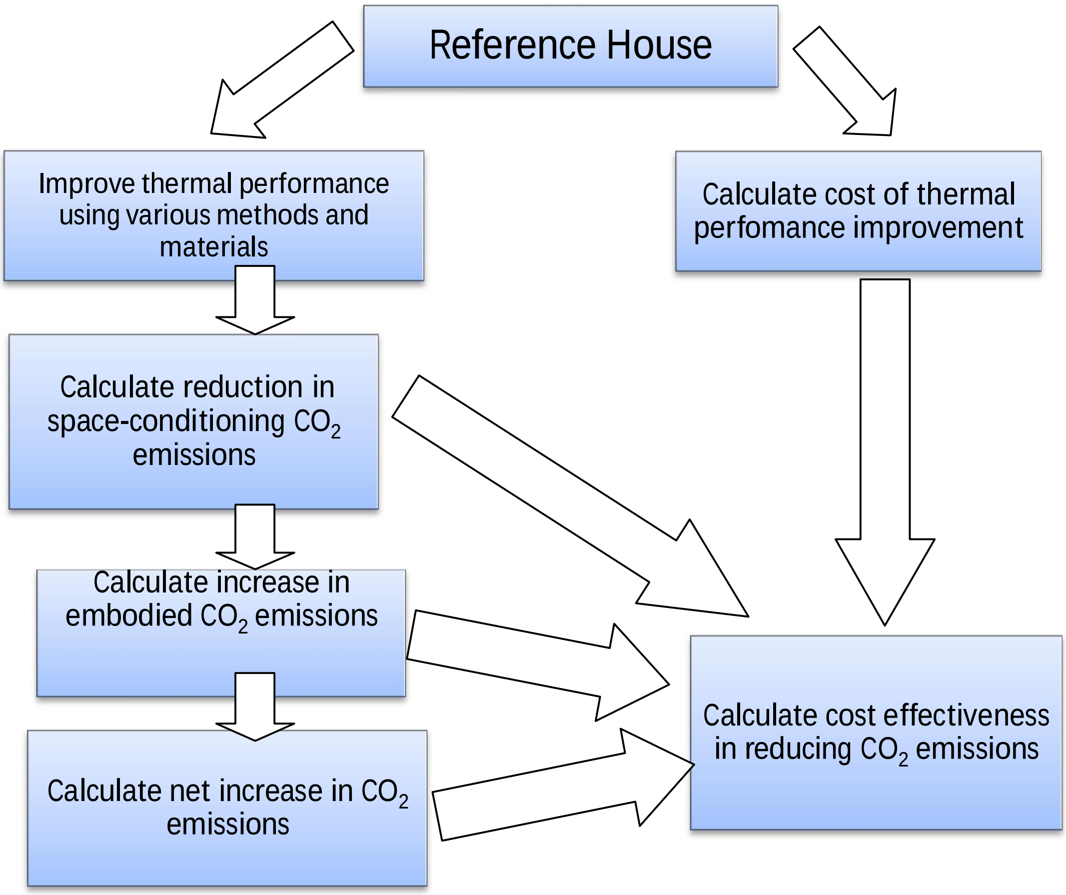
For the first measure, the cost of a design's thermal performance improvement was divided by the theoretical annual reduction in heating and cooling emissions that it provided. The designs were then ranked in order of cost effectiveness.

For the second measure, the cost of a design's thermal performance improvement was divided by the annualized (based on a 25-year life) increase in embodied emissions (that is, the embodied emissions associated with the thermal performance improvement).

For the third measure, the cost of a design's thermal performance improvement was divided by the sum of the theoretical annual reduction in heating and cooling emissions and the annualized increase in embodied emissions of the design. A 25-year life is short compared to most lifecycle energy studies. However, this study is concerned with CO_2-e, and the emission intensity of electricity is likely to change in the next 25 years, most likely becoming less intensive. Extending the study beyond that timeframe would require making assumptions about the source of electricity generation increasing the uncertainty of the results.

4.11 SUMMARY

This Chapter has described the research methods used to address the objective of the study and to answer a number of research questions. The flowchart below summarises the sequence of the steps described. The following Chapter presents the results derived from the research method presented.


Reference House
Improve thermal performance using various methods and materials
Calculate cost of thermal perfomance improvement
Calculate reduction in space-conditioning CO_2 emissions
Calculate increase in embodied CO_2 emissions
Calculate net increase in CO_2 emissions
Calculate cost effectiveness in reducing CO_2 emissions

CHAPTER 5 – RESULTS

5.1 INTRODUCTION

The previous chapter outlined the basis for the selection of the Reference houses. Methods to improve their thermal performance, and the practical limitations of each method were described. Assessing the thermal performance of the Reference houses that resulted from each design modification required a simulation software program that met certain criteria. These criteria were established while the shortcomings of the selected software were also outlined. The methods used to estimate the capital costs as well as embodied energy of each thermal performance improvement were provided. Finally, a method for calculating the cost effectiveness of thermal performance improvements in saving CO2-e emissions was proposed.

The aim of this chapter is to develop sets of data on which the hypothesis can be tested. The results and relevant data are presented in the following sections:

- The capital cost of improving thermal performance
- Embodied energy versus thermal performance
- Capital cost versus embodied energy
- A comparison of cost effectiveness rankings of embodied and space-conditioning CO_2-e savings
- A comparison of cost effectiveness rankings of embodied, space-conditioning and net CO_2-e savings
- Capital cost and net savings in emissions
- Sensitivity Analysis

The results will also enable the key research objectives to be met, namely determining the most cost effective methods of improving the thermal performance of houses in a cool-temperate climate, and to enable the evaluation of a range of solutions for achieving thermally efficient houses

5.2 THE CAPITAL COST OF IMPROVING THERMAL PERFORMANCE

This section presents the results of the studies examining the capital cost of incremental thermal performance improvements to the Reference houses. It comprises the following:

- The cost of improving the thermal performance of the Reference Houses to achieve ratings of between 5-6, 6-7, and 7-8 stars;
- The cost and associated savings in heating/cooling CO_2-e resulting from the thermal performance of each Reference House, for each star band; and
- The rankings of the cost-effectiveness in reducing CO_2-e of each thermal performance improvement.

5.2.1 Design modifications to reference houses

Table 5.1 shows the star rating of the Reference Houses as assessed by AccuRate. Both the timber floor and slab-on-ground houses met the minimum 4-star requirement of the 2008 deemed-to-satisfy provisions of the BCA. However, the timber floor houses did not achieve a 4-star rating when assessed by AccuRate. The Kingston and Crimson slab-on-ground houses rate 0.5 star higher than the respective timber floor houses. The Hickman slab-on-ground house rates 0.6 star higher than the timber floor house.

Table 5.1 – Star Ratings of the Reference Houses

	Star Rating	
House	**Timber floor**	**Slab-on ground**
Kingston	3.8	4.3
Crimson	3.6	4.1
Hickman	3.8	4.4

Tables 5.2, 5.3 and 5.4 show the range of design modifications used to improve incrementally the thermal performance of the Reference Houses.

Table 5. 2 – Design modifications

Code	Description of change	Code	Description of change
T1	Tiles in lieu of carpet in living/dining and bedrooms	L1	Take out downlights, make external walls darker
T2	Tiles in lieu of carpet in living/dining room	F1	High span beams

Table 5. 3 – Insulation modifications

Code	Description of change	Code	Description of change
R1	Floor insulation R3.0, wall insulation R2.5 Ceiling insulation R5.0	R13	Floor insulation R6.0, Wall insulation R2.5, Ceiling insulation R5.0
R2	Floor insulation R6.0, wall insulation R6.0, ceiling insulation R8.0	R14	Floor insulation R6.0, wall insulation R2.5, Ceiling insulation R5.0
R3	Floor insulation R3.0, wall insulation R6.0, ceiling insulation R8.0	C1	Slab with R1.0 under insulation, wall insulation R2.5, ceiling insulation 5.0
R4	Floor insulation R10, wall insulation R10, ceiling insulation R12	C2	Slab with R1.0 under insulation, wall insulation R6.0, ceiling insulation R8.0
R5	Floor insulation R5.0, wall insulation R6.0 ceiling insulation R8	C3	150mm slab with R3.0 under insulation, wall insulation R2.5, ceiling insulation R5.0
R6	Wall insulation R2.5	C4	Slab with R2.0 under insulation, wall insulation R6.0, ceiling insulation R8.0
R7	Wall insulation R2.5, Ceiling insulation R5.0	C5	150mm slab with R3.0 under insulation, wall insulation R10, ceiling insulation R12
R8	Floor insulation R1.5	C6	200mm slab with R3.0 under insulation, wall insulation R10, ceiling insulation R12.
R9	Wall insulation 6.0, ceiling insulation R8.0	C7	200mm slab with R3.0 under insulation, wall insulation R2.5, ceiling insulation R5.0
R10	Floor insulation R3.0, wall insulation R4.0, ceiling insulation R5.0	C8	200mm slab, Floor insulation R3.0, Wall insulation R8.0, Ceiling insulation R10.
R11	Floor insulation R8.0, wall insulation R8.0, ceiling insulation R10.0	C9	Slab R1.0
R12	Floor insulation R2.5		

Table 5. 4 – Window modifications

Code	Description of change	Code	Description of change
W1	Reduce windows in living/dining and bedrooms to 20% of wall area (approx 50% area reduction)	W7	Argon filled, doubled glazed windows (timber)
W2	Bedroom 1 (window 1.6m2), Bedroom 2 (window 1.44m2), Living room south window ($1m^2$)	W8	Triple glaze living/dining and bedroom windows (timber frame)
W3	Double glaze living/dining windows	W9	Reduce windows in living/dining room to 20% of wall area
W4	Double glaze living/dining and bedrooms windows	W10	Weatherstrip windows
W5	Timber windows	W11	Triple glaze liv/dining room (timber frame)
W6	Thermally broken aluminum windows	W12	Thermally broken aluminium double glazed windows

5.2.2 Cost versus thermal performance (4- 8 stars)

Figures 5.1, 5.2 and 5.3 below show plots of the cost of the various design modifications versus thermal performance aimed at improving the thermal performance, up to 8 stars, of the 4-Star Kingston, Crimson, and Hickman Reference Houses respectively. The cost of improvement is relative to the cost of the 4-Star Reference Houses. The plots do not differentiate between timber floor and slab-on-ground designs. A total of sixty-four design modifications were made to the timber floor and slab-on-ground designs of each Reference House. However, as shown in figures 5.4 and 5.5, a particular design modification does not necessarily result in the same star rating for each house. Therefore, for the three Reference Houses, the number of designs for each star band varies.

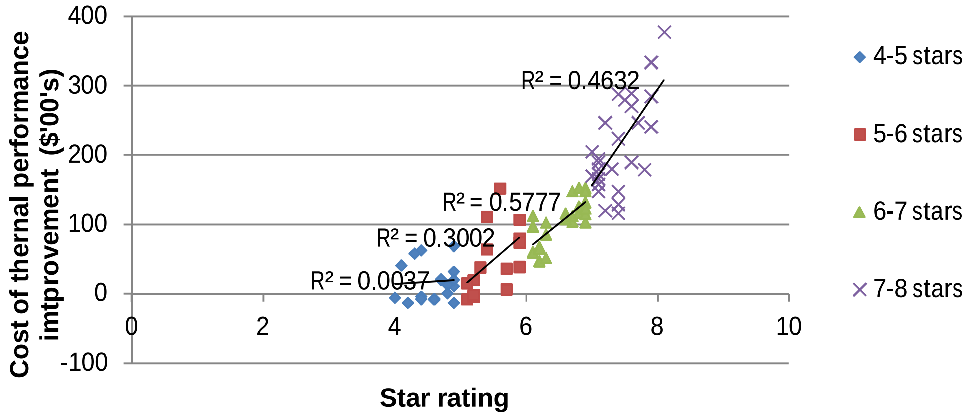


Figure 5.1 – Cost versus thermal performance (Kingston house)

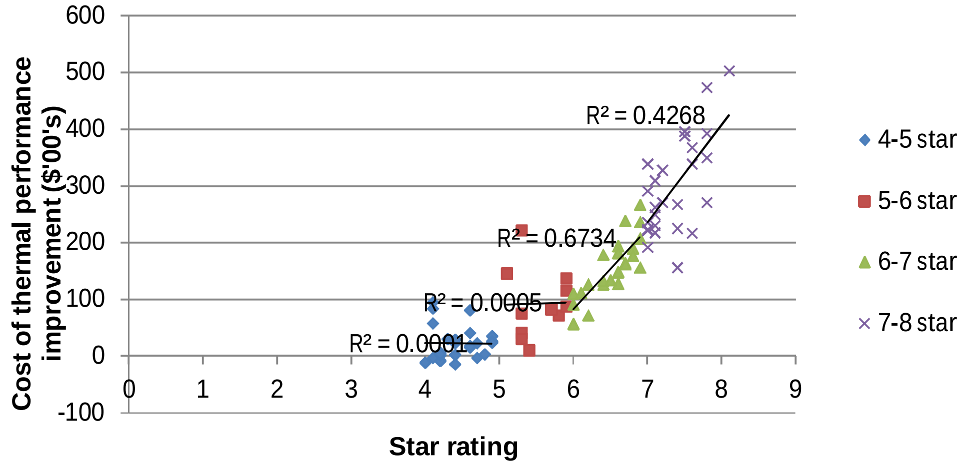


Figure 5.2 - Cost versus thermal performance (Crimson house)

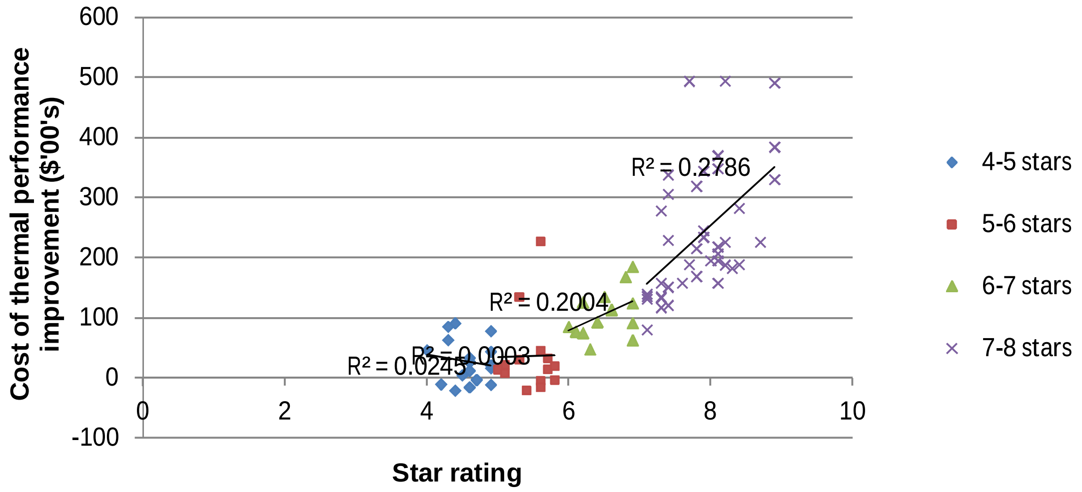


Figure 5.3 – Cost versus thermal performance (Hickman house)

Kingston

Figure 5.1 shows that the correlation between cost and improved thermal performance is stronger for designs in the 6-7 and 7-8 star bands than it is for designs in the 4-5 and 5-6 star band range, although overall it is weak[13]. In most cases designs with a higher star rating are more expensive. However, the plot also shows that 4-5 and 5-6 star ratings can be achieved for less cost than the 4 star floor Reference Houses; 6-7 star ratings can be achieved for less cost than 5-6 and 4-5 star designs; and 7-8 star ratings can be achieved for less cost than 6-7 and 5-6 star designs.

Crimson

Similarly, Figure 5.2 shows that the correlation between cost and improved thermal performance for designs in the 4-5 and 5-6 star bands is weak, while stronger for designs in the 6-7 and 7-8 star bands. The plot also shows that 4-5 star ratings can be achieved for

[13] The magnitude of the correlation coefficient determines the strength of the correlation and the sign (+ or -) of the correlation coefficient determines whether the correlation is positive or negative. While there are no hard and fast rules for describing correlational strength, in this thesis the level of strength is defined by the following ranges: 0 < |r| < .3 weak correlation; .3 < |r| < .7 moderate correlation ; |r| > 0.7 strong correlation.

less cost than the 4-star Reference Houses. However, unlike for Kingston, 5-6 star ratings cannot be achieved for less cost than the 4 star Reference Houses. Nevertheless, 5-6 and 6-7 star designs can be achieved for less cost than 4-5 star designs, and 7-8 star ratings can be achieved for less cost than 5-6 and 6-7 and star designs.

Hickman

As for the Kingston and Crimson houses, Figure 5.3 shows the correlation between cost and thermal performance is stronger for designs in the higher star band ranges. However, the correlation is weaker for the 6-7 and 7-8 stars designs than it is for the Kingston and Crimson houses. The plot also shows that 4-5 and 5-6 star ratings can be achieved for less cost than the 4 star Reference houses. 5-6, and 6-7 star designs, and one 7-8 star design, can be achieved for less cost than 4-5 star designs.

5.2.3 Cost versus thermal performance (5-6 stars)

Thermal performance comparisons of design modifications

Sixteen design modifications (8 each to timber floor and slab-on-ground houses) were made to the Kingston Reference Houses in order to achieve a rating of between 5 and 6 stars (see Table 5.5). Figures 5.4 and 5.5 show the star ratings that those modifications achieve for each Reference House. For the slab-on-ground houses, in most cases a design modification provides a higher star rating for the Hickman house than it does for the Kingston house and, in most cases a design modification provides a greater star rating for the Kingston house than it does for the Crimson house.

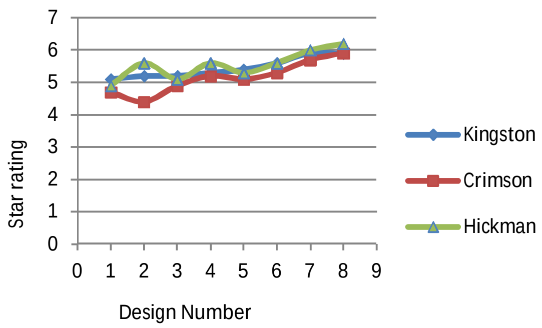


Figure 5.4 - 5-6 star timber

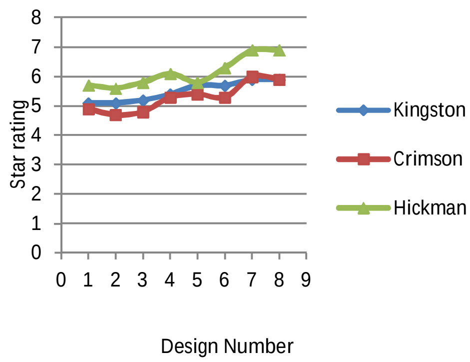


Figure 5.5 – 5-6 star slab-on-ground

Table 5.5 shows the average star rating the design modifications achieve for the timber and slab-on-ground Reference Houses. For the slab-on-ground designs, the Hickman house achieves an average star rating 0.6 and 0.8 higher than the average star ratings of the Kingston and Crimson houses respectively. For the timber floor houses, the Hickman and Kingston have the same average star rating of 5.5, which is 0.2 stars higher than for the Crimson house.

Table 5.5 - Average star rating of design modifications (5-6 star band)

	Average star rating	
House	**Timber floor**	**Slab-on-ground**
Kingston	5.5	5.5
Crimson	5.2	5.3
Hickman	5.5	6.1

There are cases where a design modification that improves the thermal performance (relative to another design) of one house, leads to a decrease in thermal performance for another house. For example, for the slab-on-ground houses, Design 5 provides a lower level of thermal performance than Design 4 for Hickman and Crimson, whereas the reverse is true for Kingston. This indicates that rules-of-thumb for improving thermal performance to achieve 5-6 stars, do not necessarily apply to the houses.

Kingston (5-6 stars)

Table 5.6 shows all designs resulting from various combinations of changes and their respective cost to achieve a rating between 5 and 6 stars. The costs of improvement are relative to the 4 star Reference Houses.

Table 5.6 – Cost of thermal performance improvements from 4 stars to 5-6 stars (Kingston)

Design (Star Rating, Cost)	**Changes in building fabric**	**Design (Star Rating, Cost)**	**Changes in building fabric**
1. 5.1, $15	(W1) (W4)	**9**. 5.4, $64	(W2) (R9)
2. 5.1, -$8	(W1) (R6)	**10**. 5.6, $152	(R4)
3. 5.1, $15	(L1) (R8) (R6)	**11**. 5.7, $6.4	(W1) (C1)
4. 5.2, $-1.65	(R8) (W1)	**12**. 5.7, $36.30	(W2) (W3) (R7)
5. 5.2, $20	(R12) (L1) (R6)	**13**. 5.9, $74	(C2) (W2)
6. 5.2, - $4.4	(W1) (R7)	**14**. 5.9, $39	(R12) (L1) (R6) (W5)
7. 5.3, $32	(R1)	**15**. 5.9, $80	(W2) (W5) (R9)
8. 5.4, $111	(R2)	**16**. 5.9, $107	(W2) (R2)

Note: $ in hundreds

Figure 5.6 shows the cost of achieving 5-6 star ratings, differentiating the timber floor and slab-on-ground designs. While in most cases, the higher a design's star rating, the more expensive it is, for both floor types, a rating between 5 and 6 stars was achieved for less cost than the 4-star Reference House. This was made possible by reducing the glazing area, which more than offsets the additional cost of any extra insulation that was used in each case. None of the low-cost designs used double-glazing.

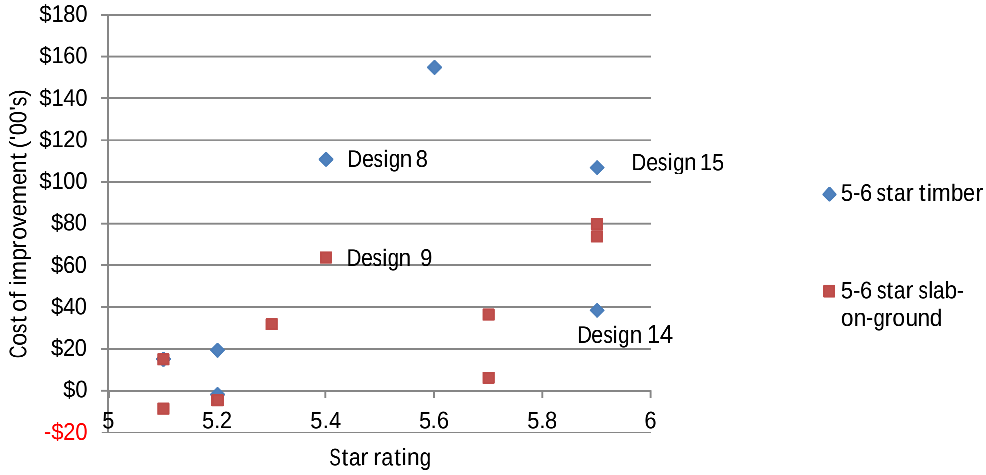


Figure 5.6 - Cost versus thermal performance (5-6 star Kingston)

The correlation between cost and thermal performance is weak for both floor types, although it stronger for the slab-on-ground designs. There is a considerable difference in cost between some designs that achieve the same level of thermal performance. For example, the timber-floor Design 8 and the slab-on-ground Design 9 both achieve 5.4 stars. However, the slab-on-ground design is $4,700 less expensive. The timber floor design has high levels of floor, wall and ceiling insulation. The slab-on-ground design has high levels of wall and ceiling insulation, the cost of which is partly offset by the reduced glazing area. Furthermore, all else being equal, the slab-on-ground design without slab insulation has an approximately 0.5 higher star rating than the timber floor design without floor insulation.

The average increase in construction cost is less for the slab-on-ground designs than for timber floor designs. However, there are timber floor designs that cost less than slab-on-ground designs of the same star rating. For example, the timber floor Design 14 is $4,100 less expensive than the slab-on-ground floor Design 15. The timber floor design achieved a 5.9 star rating by changing the external wall colour from light to dark and removing the downlights (L1, table 1), adding R2.5 floor insulation, and increasing wall insulation to R2.5. Also, window frames were changed from aluminium to timber, which increased the design's star rating by 0.7 stars. Adding L1 (no cost change) to this design increased its star rating by 0.6 stars. The higher cost of the slab-on-ground design is attributable to the high levels of wall and ceiling insulation.

For Design 6 if the living/dining and bedroom windows had been double-glazed instead of the window areas being reduced, the same star rating (5.2 stars), would have been achieved. Therefore, reducing single-glazed windows to a size that does not compromise view or natural light can provide the same thermal performance improvement as double-glazing but for much less cost. This demonstrates the trade-off in the size of single-glazed windows needed to achieve the same thermal performance as double-glazed windows.

Design modifications that include reduced glazing area are cost-effective in achieving a star rating of between 5 and 6 stars because thermal performance increases while construction cost decreases. A near 6 star rating can be achieved for the timber and concrete floor houses without double-glazing if the glazing area is reduced. If the window area and type (single, clear glass and aluminium frames) are unchanged, and downlights remain, relatively high levels of insulation were needed to achieve higher star ratings within this star band.

Crimson (5-6 stars)

Table 5.7 shows all designs resulting from various combinations of changes and their respective cost to achieve a rating between 5 and 6 stars. The costs of improvement are relative to the 4-Star Reference Houses.

Table 5.7 – Cost of thermal performance improvements from 4 stars to 5-6 stars (Crimson)

Design (Star Rating, Cost)	Changes in building fabric	Design (Star Rating, Cost)	Changes in building fabric
1. 5.1 $141	(R2)	**7.** 5.4, $12	(W1) (C1)
2. 5.2, $45	(R1)	**8.** 5.7, $82	(R12) (R6) (L1) (W5)
3. 5.3, $73	(W2) (R9)	**9.** 5.8, $79	(W2) (W3) (R1)
4. 5.3, $45	(W2) (W3) (R7)	**10.** 5.9, $136	(W2) (R2)
5. 5.3, $37	(W2) (R1)	**11.** 5.9, $97	(W2) (R1) (W4)
6. 5.3, $-14	(R4)	**12.** 5.9, $122	(W2) (W5) (R9)

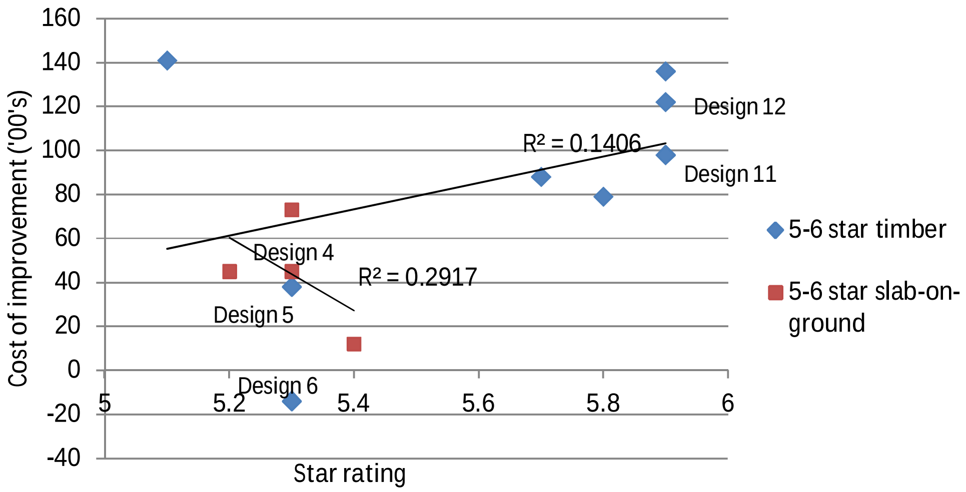


Figure 5.7 – Cost versus thermal performance (5-6 stars Crimson House)

Figure 5.7 shows the cost of achieving 5-6 star ratings, differentiating the timber floor and slab-on-ground designs. The correlation between cost and thermal performance is weak for both floor types. There is one 5 to 6 star design that costs less than the 4-Star Reference House. The increase in thermal performance for negative cost was achieved by reducing the glazing area in the living/diningroom. It would have been possible for more designs to have reached a 5-6 star level of thermal performance by adopting a reduced glazing area option and removing downlights.

As for the Kingston house, Figure 5.7 shows that there is a considerable difference in cost between designs that achieve the same level of thermal performance. For example, the timber floor Designs 5 and 6 both achieve 5.3 stars, though the latter costs $5,200 less. This design has high levels of floor, wall and ceiling insulation. No other design modifications were made. Comparing these two designs shows that without reducing glazing area or improving its R-value, there is limit to the extent to which increasing insulation levels will provide an improvement in thermal performance.

The average cost of achieving 5-6 stars is less for slab-on-ground designs than for timber floor designs. However, there are timber floor designs that cost less than slab-on-ground designs with the same or lower star ratings. For example, the timber floor Design 5 is $700 less expensive than the slab-on-ground floor Design 4 of the same star rating. Both designs have the same window area, window frame and glazing type, and the same levels of wall and ceiling insulation. However, the timber floor design has R3.0 floor insulation and the slab-on-ground design has double-glazed living/dining room windows. The addition of R3.0 floor insulation to the timber floor design provides the same star rating as the addition of double-glazing to the slab-on-ground design, but for less cost.

The timber floor Designs 11 and 12 both have a 5.9 star rating, though Design 11 is $2,400 less expensive. Both designs have the same glazing area. Design 11 has double-glazed windows in the living/dining room and bedrooms, while none of Design 12's windows were double-glazed. However, timber window frames were used in lieu of aluminium frames. Thermal simulation showed that if the single-glazed timber frame windows were changed to aluminium frames, and the living/dining room and bedroom windows were double-glazed, the star rating of the design would not change. In this case, because the timber windows are less expensive and provide the same level of thermal performance as double-glazed aluminium windows, they are more cost effective. The difference in cost between the two designs can be attributed to the significantly higher levels of wall and ceiling insulation used in the Design 12.

Hickman (5-6 stars)

Table 5.8 shows all designs resulting from various combinations of changes and their respective cost to achieve a rating between 5 and 6 stars. The costs of improvement are relative to the 4-Star Reference Houses.

Table 5.8 – Cost of thermal performance improvements from 4 stars to 5-6 stars (Hickman)

Design (Star Rating, Cost)	Changes in building fabric	Design (Star Rating, Cost)	Changes in building fabric
1. 5.0, $14	(C9)	**8.** 5.6, $227	(R4)
2. 5.1, $22	(R6) (R12) (L1)	**9.** 5.6, -$4	(W1) (R8)
3. 5.1, $8	(W3) (W9)	**10.** 5.6, -$15	(W1) (R6)
4. 5.3, $25	(C1)	**11.** 5.7, $28	(W2) (R1)
5. 5.3, $135	(R2)	**12.** 5.7, $15	(W4) (W1)
6. 5.4, -$21	(W1)	**13.** 5.8, $6	(W1) (C1)
7. 5.6, $40	(R1)	**14.** 5.8, -$9	(W1) (R7)

Figure 5.8 shows a plot of the cost of achieving a rating of between 5 and 6 stars, differentiating the timber floor and slab-on-ground designs. The correlation between thermal performance and cost is very weak for both floor types.

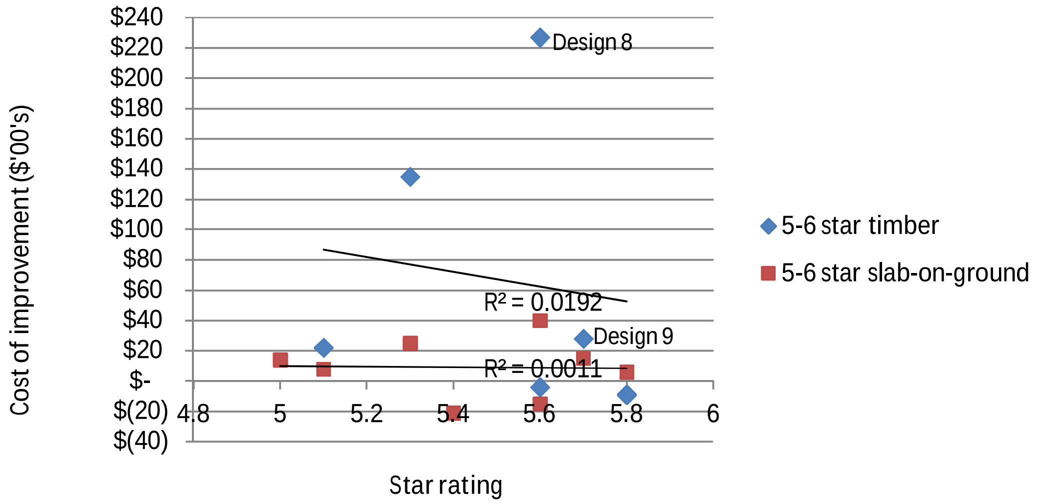


Figure 5.8 – Cost versus thermal performance (5-6 star Hickman House)

Two timber floor designs and two slab-on-ground designs cost less than the 4-star Reference House. The glazing area of each one of the negative cost designs was reduced. The two designs with the highest star rating were among the lowest cost designs, while the most expensive design achieved a 5.6 star rating only. Because of the Reference Houses' extensive area of north glazing, the design change (W1) represents a larger percentage reduction in total building cost than it does for the other two houses. Design 6 has achieved a 5.4 star from this change alone. In addition to (W1), the three other negative cost designs either had floor insulation added or wall and/or ceiling insulation levels increased modestly. One of the timber floor designs had R1.5 floor insulation added while the other designs had the level of wall and ceiling insulation increased. Adding floor insulation to the timber floor design provided a similar level of thermal performance improvement as increasing the levels of wall and ceiling insulation did to the slab-on-ground designs.

As for the Kingston and Crimson houses, there is a considerable difference in cost between designs that achieve the same level of thermal performance. For example, the timber floor Designs 8 and 9 both achieve 5.6 stars. However, the former costs $23,100 more. Design 8 has very high levels of floor, wall and ceiling insulation, which contribute to the high cost. No other design changes were made. The less expensive design had R1.5 floor insulation added and the window areas reduced, which more than offset the cost of the floor insulation.

While the average cost of achieving a rating between 5 and 6 stars is less for slab-on-ground designs than it is for timber floor designs, there are timber floor designs that cost less than slab-on-ground designs with the same or lower star ratings. The timber floor designs had their window areas reduced. Except for one of the slab-on-ground designs, the window areas remained the same and their thermal performance was improved by increasing the insulation levels. The slab-on-ground design with reduced glazing area has also been double-glazed.

5-6 star summary

For each of the three houses, on average it costs less for the slab-on-ground designs to achieve 5-6 stars than it does for the timber floor houses (see Table 5.9 below). This is partly because, all else being equal, a slab-on-ground design without slab insulation has an approximately 0.5 star rating higher than the timber floor design without floor insulation. However, timber floor designs can achieve the same, or higher star rating, as slab-on-ground designs for less cost.

Table 5.9 - Average increase in construction cost (5-6 star)

House	Timber floor	Slab-on-ground
Kingston	4% ($57/m2)	2% ($30/m2)
Crimson	6% (86/m2)	2% ($25/m2)
Hickman	4% ($52/m2)	0.5% ($7m2)

The results only show the cost of design modifications that achieve a rating between 5 and 6 stars. Each design modification involved more than one change (see Tables 5.6, 5.7.and 5.8). While not shown, thermal simulations of each 4-Star timber floor Reference House revealed that installing R3.0 floor insulation provided a greater increase in thermal performance than double-glazing the dining/living room and bedroom windows for approximately one-third of the cost. Therefore insulating timber floors is a cost effective first measure in improving the thermal performance of the 4-star Reference House. The potential of other thermal performance improvements is not realised until this is undertaken.

Thermal simulations of all designs showed that L1 would provide between a 0.5-0.7 increase in star rating to each one, greatly improving the cost effectiveness of their respective thermal performance improvements. **Note:** The result would be that approximately 50% of the 5-6 star designs would become 6-7 star designs for no extra cost.

Cost versus savings in heating/cooling CO_2-emissions (5-6 star band range)

Figure 5.9 shows the cost of thermal performance changes versus the theoretical savings in CO_2 emissions they provide compared to the Kingston, Crimson and Hickman 4-star Reference Houses, respectively. The annual theoretical savings in space-conditioning energy that each design provides, relative to the 4-star reference houses, have been converted to savings in CO_2-emissions.

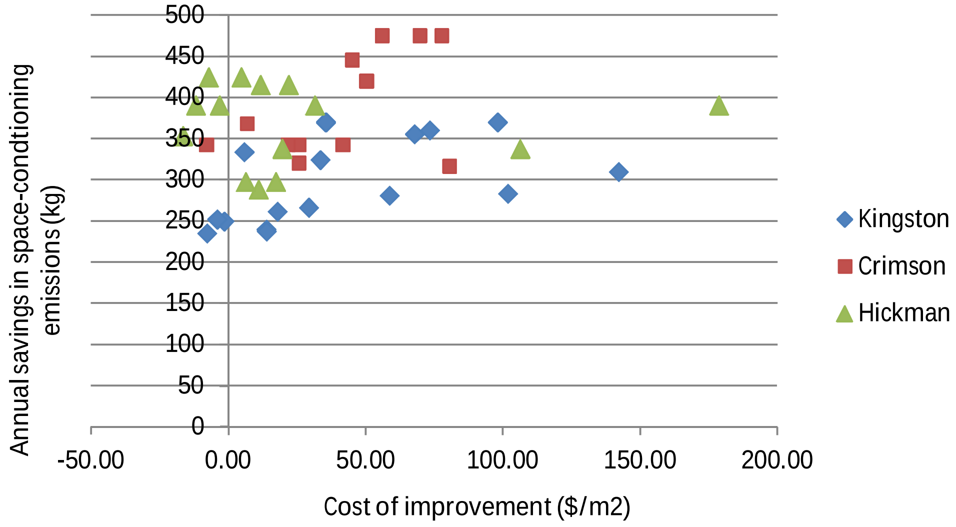


Figure 5.9 – Cost versus savings in CO_2-e (5-6 star band range)

Table 5.10 shows that on average, $1000 spent on thermal performance improvements to achieve 5-6 stars provides the greatest saving in CO_2-e for the Hickman house at 107kg per annum.

Table 5.10 – Average cost of achieving 5-6 stars and resultant savings in CO_2-emissions

	Average cost of achieving 5-6 stars	Average CO_2-e saved (kg)/per annum	CO_2-e saved per $1000 (per annum)
Kingston	$4,620 ($42/m2)	296kg	64kg
Crimson	$7257 ($41/m2)	389kg	53kg
Hickman	$3429 ($27/m2)	368kg	107kg

Cost effectiveness in reducing space-conditioning CO_2-e (5-6 stars)

Figure 5.10 shows the cost effectiveness ranking of thermal performance improvements for the three houses. In this case, cost effectiveness is the ratio of $ spent divided by kg $C0_2$-e saved (per annum). The lower the ratio, the more cost effective the measure. However, the most cost effective design is not necessarily the least expensive or the one that saves the most CO_2-e. For the purposes of calculating cost effectiveness, the sixteen design modifications are those that achieve a rating of between 5 and 6 stars for the Kingston houses. As shown in figures 5.4 and 5.5, when the Crimson and Hickman houses adopt the same modifications, a rating of between 5 and 6 stars is not necessarily the outcome.

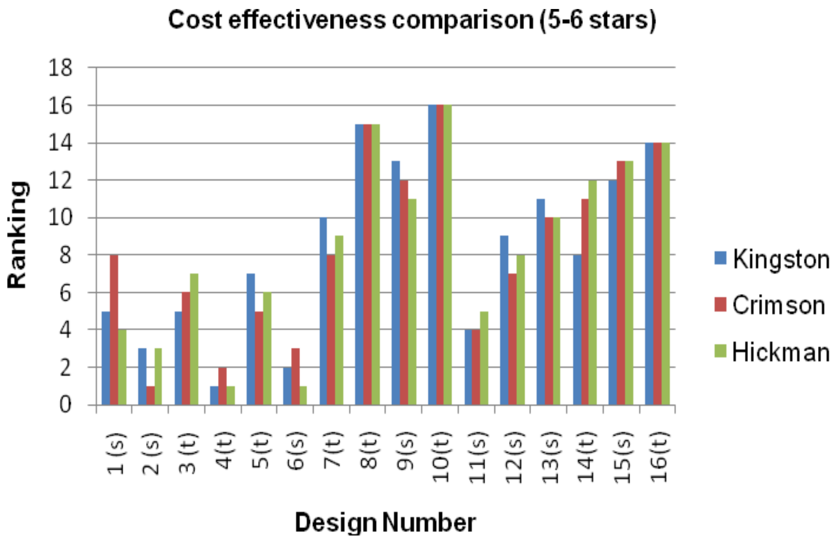


Figure 5.10 - Cost effectiveness of design modifications in saving space conditioning CO_2-e

While the star rating that the design modifications provide for each house varies (see figures 5.4 and 5.5), there is little variation in the cost effectiveness ranking of the design modifications between the three houses.

The most cost effective[14] designs are 2, 4 and 6, which provide a ranking of between 1 and 3 for the houses. These are the three lowest cost designs for each house. Each design modification included reducing the window area. In addition, Design 2 has double-glazed dining/living room and bedroom windows. Design 4 has R1.5 floor insulation, and Design 6 has R2.5 wall and R5.0 ceiling insulation.

The least cost effective (lowest ranked) design for all houses is Design 10, which has high levels of floor, wall and ceiling insulation, with no other design modifications made. Design 10 is also the most expensive design for each house

The greatest difference in ranking a particular design provides between the houses is four, for Designs 1 and 14. Design 14 is more cost effective for the Kingston house than the other houses. Design 1 is more cost effective for the Hickman house than the other houses.

5.2.4 Cost versus thermal performance (6-7 stars)

Thermal performance comparisons

Twenty-two design modifications were made to the Kingston Reference Houses in order to achieve a rating between 6 and 7 stars. (These are shown in Table 5.12). Figures 5.11 and 5.12 show plots of the star ratings that those designs achieve for each Reference House.

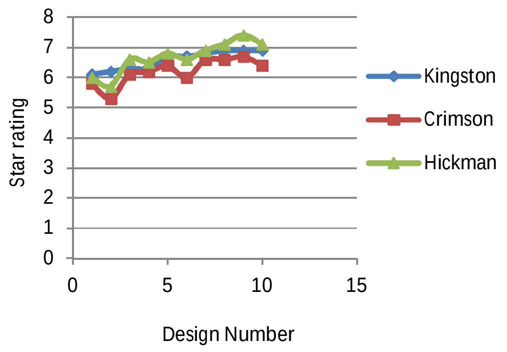


Figure 5.11 - Star rating comparison (timber floor)

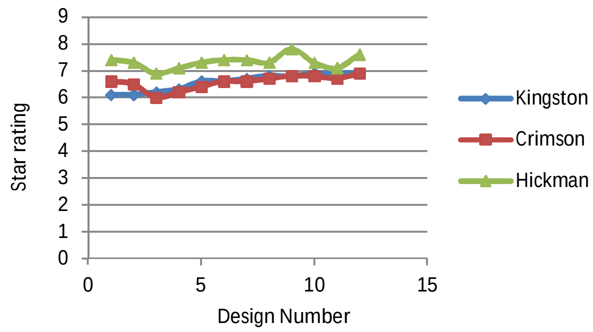


Figure 5.12 – Star rating comparison (slab-on-ground)

[14] Where the most cost effective design is ranked 1 and the least cost effective design is ranked 16.

For the slab-on-ground houses, design modifications provide a greater thermal performance improvement for the Hickman house than for the Crimson and Kingston houses. On average, slab-on-ground designs rate 0.7 stars higher for the Hickman house than for the other two houses (see Table 5.11 below). A majority of the slab-on-ground design modifications could be considered rules-of-thumb for the three houses. That is, for each house, a given design modification provides a similar level of thermal performance relative to other design modifications.

On average, timber floor designs rate 0.4 and 0.8 stars higher for the Hickman house than for the Kingston and Crimson house, respectively.

Table 5.11 - Average star rating of design modifications (6-7 star band)

House	Timber floor	Slab-on-ground
Kingston	6.6	6.6
Crimson	6.2	6.6
Hickman	7	7.3

For the timber floor houses, the lines plotting the thermal performance improvement of the design modifications for the houses do not display the same pattern as each other. Therefore, rules-of-thumb to achieve a rating of between 6 and 7 stars across different houses do not to apply in this case. Reasons for this relate mainly to the floor area and wall/floor ratio of the Reference houses and are discussed further in Section 6.1.3 of Chapter 6.

Kingston (6-7 stars)

Table 5.12 shows all designs resulting from various combinations of changes and their respective cost for the 4 star Reference house to achieve a rating of between 6 and7 stars. The costs of improvement are relative to the 4-Star Reference Houses.

Table 5.12 – Cost of thermal performance improvements to achieve 6-7 stars (Kingston)

Design (Star Rating, Cost)	Changes in Building Fabric	Design (Star Rating, Cost)	Changes in Building Fabric
1. 6.1, $60	(W2) (R1) (W3)	**12.** 6.7, $148	(W2) (R2) (W3)
2. 6.1, $112	(W9) (W3) (T1) (C7)	**13.** 6.7, $104	(W4) (W1) (R5)
3. 6.1, $97	(W9) (W3) (C2)	**14.** 6.8, $117	(W2) (R1) (W4) (T1)
4. 6.2, $68	(W2) (R1) (W4)	**15.** 6.8, $126	(W2) (W4) (C3) (T1)
5. 6.2, $47	(W2) (W3) (C1)	**16.** 6.8, $153	(W2) (W4)(R2).
6. 6.3, $52	(W2) (W4) (C1)	**17.** 6.9, $132	(W2) (W4) (C7) (T1)
7. 6.3, $86	(W2) (W4)(R13)	**18.** 6.9, $115	(W2) (W4) (C7) (T2)
8. 6.3, $103	(W2) (W4) (R10)	**19.** 6.9, $123	(W2) (C4) (W4)
9. 6.6, $108	(W2) (W3) (C2)	**20.** 6.9, $153	(W2) (W4) (R3) (W5)
10. 6.6, $116	(W2) (W4) (C2)	**21.** 6.9, $148	(W2) (W4) (R11)
11. 6.7, $112	(W2) (W4)(C2) edge insulation	**22.** 6.9, $103	(W2) (W4) (R10)

Figure 5.13 shows a plot of the cost of achieving a rating between 6 and 7 stars, differentiating the timber floor and slab-on-ground designs. The correlation between cost and thermal performance is stronger for the timber floor designs. There is a considerable difference in cost between some designs that achieve the same or a similar level of thermal performance. For example, the slab-on-ground Design 6 and the timber floor Design 8 have the same glazing area and the same windows are double-glazed. The cost difference between the two designs is attributable to the higher levels of insulation needed for the timber floor house to achieve the same star rating. The difference in insulation levels is also the reason for the difference in cost between slab-on-ground Design 15 and the timber floor Design 16

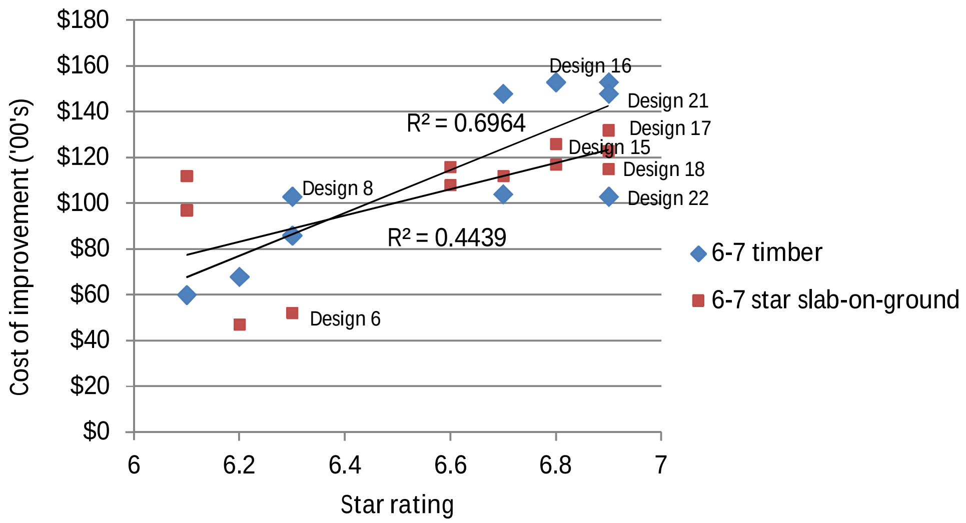


Figure 5.13 – Cost versus thermal performance (Kingston)

The average cost of slab-on-ground designs is marginally less than the average cost of timber floor designs within the 6-7 star band range (see Table 15). However, there is a 6.9 star timber floor design that costs less than three slab-on-ground designs that have the same star rating. The timber floor Design 22 was achieved with moderate levels of floor, wall and ceiling insulation. The cost of the extra insulation was partly offset by reducing the glazing area. The slab-on-ground Design 18 has the same windows double-glazed and the same window area, and similar levels of insulation as the timber floor design. Its slab thickness was increased and tiles replaced carpet in the living/dining room, explaining its higher cost.

The results show that there is a point beyond which adding extra insulation is no longer cost effective if other design modifications remain unchanged. For example, the only difference between the timber floor Designs 8 and 21 is that the insulation levels of the latter are significantly higher. Other changes, such as removing downlights or reducing glazing area, would have provided a greater thermal performance improvement, at much less cost. In the case of the two designs described, if the only design modification made was to increase insulation levels, then the design with the higher insulation levels would have achieved a marginally higher star rating.

Optimising the thermal mass of slab-on-ground designs was considered as providing potentially a low cost method of improving thermal performance. To utilize the thermal mass of the slab, Design 17 had dark tiles in lieu of carpet, and the slab was insulated and its thickness doubled. On the other hand, the less expensive slab-on-ground Design 19 with the same star rating has the same window area and glazing type as the more expensive design. However, its slab while insulated remained carpeted. Its higher wall and ceiling insulation levels provide the same level of thermal performance improvement as tiling and increasing the slab’s thickness, but for less cost.

Crimson (6-7 star)

Table 5.13 below shows all designs resulting from various combinations of changes and their respective cost to achieve a rating between 6 and 7 stars. The costs of improvement are relative to the 4-Star Reference Houses. The correlation between cost and thermal performance for both floor types is strong for the slab-on-ground designs but weak for the timber floor designs.

Figure 5.14 below shows a plot of the cost of achieving a rating of between 6 and 7 stars for the 4 star Reference house, differentiating the timber floor and slab-on-ground designs. It can be seen that the least and the most expensive designs have the lowest and highest star ratings, respectively. As for the Kingston house, there is a considerable difference in cost between some designs that achieve the same or similar level of thermal performance. For example, the slab-on-ground Design 21 and the timber floor Design 20 have the same glazing area and the same windows are double-glazed. The cost difference between the two designs is attributable to the higher levels of insulation needed for the timber floor house to achieve the same star rating as the slab-on-ground design. The difference in insulation levels is also the reason for the difference in cost between the slab-on-ground Design 17 and the timber floor Design 16.

Table 5.13 – Cost of thermal performance improvements to achieve 6-7 stars (Crimson)

Design (Star Rating, Cost)	Changes in Building Fabric	Design (Star Rating, Cost)	Changes in Building Fabric
1. 6, $128	(W2) (W4) (R13)	**13.** 6.6, $137	(W2) (R1) (W4) (W5)
2. 6, $60	(W2) (W3) (C1)	**14.** 6.6, $148	(W2) (W4) (C2)
3. 6, $88	(W2) (C2)	**15.** 6.6, $148	(W2) (W4) (C2) edge insulation
4. 6.1, $124	(W2) (R1) (W3) (W5)	**16.** 6.7, $246	(W2) (W4) (R11)
5. 6.2, $79	(W2) (W4) (C1)	**17.** 6.7, $177	(W2) (W4) (R1) (T1)
6. 6.2, $135	(W2) (W4) (R10)	**18.** 6.8, $203	(W2) (W4) (R1) (T1)
7. 6.4, $135	(W2) (W4) (R10) edge insulation	**19.** 6.8, $189	(W2) (W4) (C3) (T1)
8. 6.4, $177	(W2) (R2) (W3)	**20.** 6.9, $275	(W2) (W4) (R4)
9. 6.4, $130	(W2) (W3) (C2)	**21.** 6.9, $159	(W2) (W4) (C4)
10. 6.5, $134	(W9) (C2)	**22.** 6.9, $238	(W2) (W4) (C4) (T1)
11. 6.6, $194	(W2) (R2) (W4)	**23.** 6.7, $162	(W2) (W4) (R1) (T2)
12. 6.6, $185	(W1) (W4) (C7) (T1)	**24.** 6.9, $223	(W2)(W4) (C4) (T2)

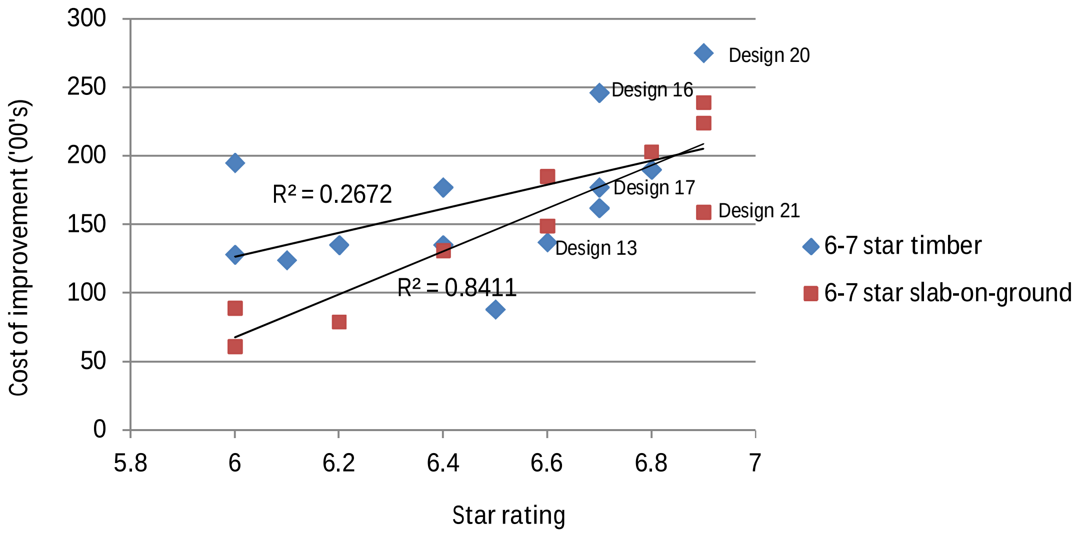


Figure 5.14- Cost versus thermal performance (Crimson)

The timber floor Designs 13 and 11 have the same glazing area and the same windows are double-glazed. The cost disparity between them is attributable to the higher levels of floor, wall and ceiling insulation that are used in the more expensive Design 11. The less expensive design achieves the same star rating by using timber-framed windows rather than the aluminium-framed windows. This design modification provides the same thermal performance improvement as the additional insulation.

The average cost of slab-on-ground designs is lower than the average cost of timber floor designs within the 6-7 star band range (see Table 17). However, the timber floor Design 13 is less expensive than two slab-on-ground designs with the same rating (6.6 stars). The timber floor design, unlike the slab-on-ground designs, has timber-framed windows as well as lower levels of insulation. The slab-on-ground designs have modifications that utilise thermal mass (dark tiles and/or thicker slab). Therefore, the timber-framed windows are providing a similar improvement in thermal performance to the timber floor house as the higher insulation and changes to utilise thermal mass provide for the slab-on-ground designs.

Hickman (6-7 star)

Table 5.14 shows all designs resulting from various combinations of changes, and their respective cost. The costs of improvement are relative to the 4-star Reference Houses.

Table 5.14 – Cost of thermal performance improvements to achieve 6-7 stars (Hickman)

Design (Star Rating, Cost)	Changes in Building fabric	Design (Star Rating, Cost)	Changes in Building fabric
1. 6, $86	(R12) (R6) (L1) (W5)	**8.** 6.6, $109	(W2) (W4) (R13)
2. 6.1, $74	(W2) (R9)	**9.** 6.6, $109	(W2) (W4)(R13)
3. 6.2, $124	(W2) (R2)	**10.** 6.8, $166	(W2) (W3) (R2)
4. 6.2, $70	(W2) (R1) (W3)	**11.** 6.9, $122	(W2) (W5) (R9)
5. 6.3, $48	(W2) (W3) (R7)	**12.** 6.9, $91	(W2) (C2)
6. 6.4, $87	(W2) (R1) (W4)	**13.** 6.9, $58	(W2) (W3) (C1)
7. 6.5, $128	(W2) (W4) (R10)	**14.** 6.9, $184	(W2) (R2) (W4)

Figure 5.15 shows a plot of the cost of achieving 6-7 star ratings, differentiating the timber floor and slab-on-ground designs.

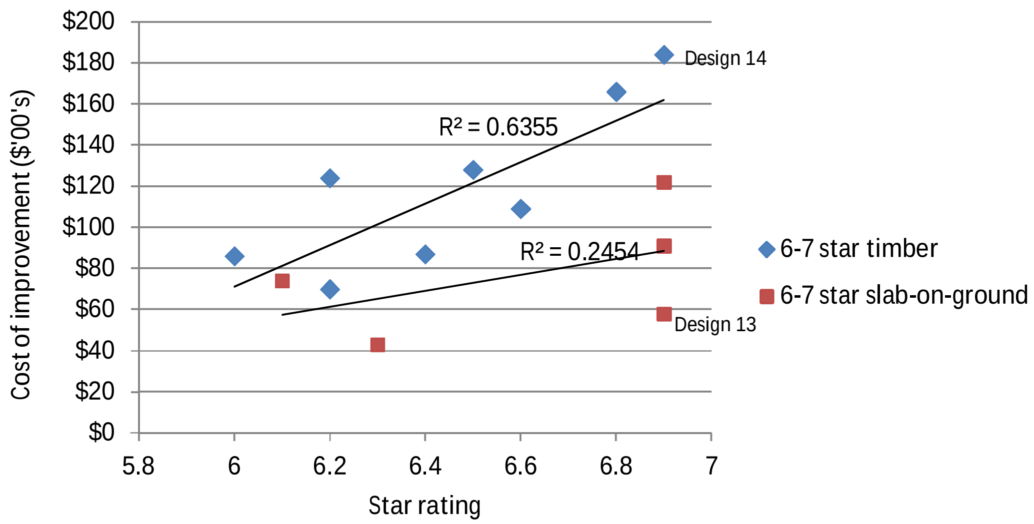


Figure 5.15- Cost versus thermal performance (Hickman)

In this case, the design with the lowest star rating (6 stars) is not the least expensive. The most expensive design has the highest star rating (6.9 stars), although three other designs with that star rating are less expensive than other designs with lower star ratings. The correlation between cost and thermal performance is much stronger for the timber floor designs than the slab-on-ground designs. For the slab-on-ground designs the correlation is very weak. The reasons for this relate to thermal performance improvements concerned with optimizing thermal mass. While these improvements are expensive, they do not necessarily lead to a higher star rating than less expensive ones. This is explained further in Section 6.2.1 of Chapter 6. The average cost of slab-on-ground designs is less than that of timber floor designs.

The slab-on-ground Design 13 achieves 6.9 stars and is less expensive than all timber floor designs. Its glazing area was reduced and the living/dining room windows were double-glazed. Moderate levels of floor, wall and ceiling insulation were used. In contrast, the timber floor Design 14 of the same star rating is approximately $12,600 more expensive. It has the same glazing area, although in addition the bedroom windows are double-glazed. High levels of floor, wall and ceiling insulation were used as well.

6-7 star summary

For each of the three houses, on average it costs less for the slab-on-ground designs to achieve a rating of between 6 and7 stars than it does for the timber floor houses (see Table 5.15 below). However, the percentage point difference between the increase in cost of the timber floor and slab-on-designs for the Kingston and Crimson houses is smaller than it was for the 5-6 star band range. For the Hickman house, the percentage point difference in the increase in cost between the timber floor and slab-on-designs for the 5-6 and 6-7 star band range is very similar (0.1 of a percentage point difference).

Table 5.15 – Average increase in construction cost (6-7 stars)

HOUSE	Timber floor	Slab-on-ground
Kingston	8% ($103/m2)	7% ($96/m2)
Crimson	7% ($95/m2)	6% ($87/m2)
Hickman	7% ($93/m2)	5% ($61/m2)

In this star band range, double-glazing the bedroom windows in combination with other measures provides a similar level of thermal performance to increasing insulation levels moderately in combination with other measures, but at less cost. The results show also that for each house, and depending on the other design modifications, increasing slab thickness and tiling to add and utilize thermal mass, provides very little thermal performance improvement.

Cost versus space heating/cooling CO_2-e emissions (6-7 stars)

Figure 5.16 shows a plot of the cost of thermal performance changes versus the annual theoretical savings in space-conditioning CO_{2-} emissions they provide for the Kingston, Crimson and Hickman 4-star Reference Houses, respectively.

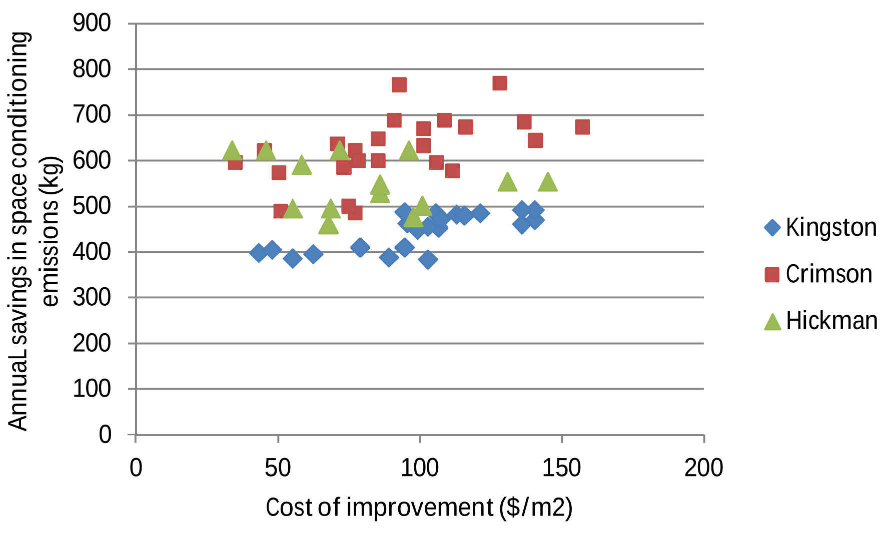


Figure 5.16- Comparison of cost versus annual savings in space-conditioning emissions

Table 5.16 shows that on average, $1000 spent on thermal performance improvements to achieve 5-6 stars provides the greatest saving in CO_2-e for the Hickman house at 53kg per annum. Compared to the 5-6 star band, it costs more for each house to save a kg of CO_2-e.

Table 5.16 - Average cost of achieving a rating between 6 and 7 stars and resultant savings in CO_2-e

HOUSE	Average cost of improvement	Average CO_2-e saved kg/per annum	CO_2-e saved per $1000 (per annum)
KINGSTON	$10,890 ($99/m2)	446 kg	41kg
CRIMSON	$16,107 ($91/m2)	627 kg	39kg
HICKMAN	$10,414 ($82/m2)	550 kg	53kg

Cost effectiveness in reducing space-conditioning CO_2-e (6-7 stars)

Figure 5.17 shows the cost effectiveness ranking of thermal performance improvements for the three houses. For the purposes of calculating cost effectiveness, the design modifications are those that achieve a rating of between 6-7 stars for the Kingston Reference houses.

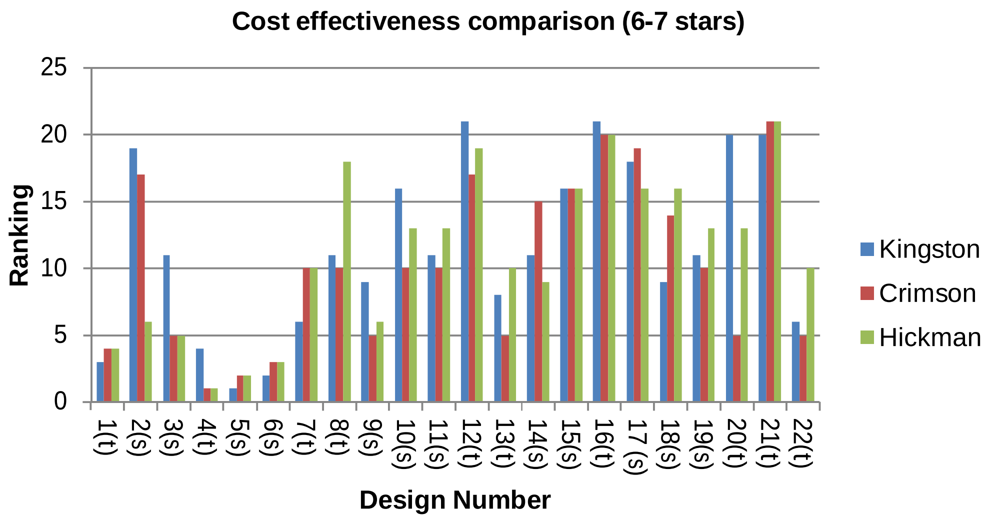


Figure 5.17 - Cost effectiveness of design modifications in saving space-conditioning CO_2-e

Compared to the 5-6 star band, there is a greater variability in rankings that a certain design achieves for each of the three houses (the average range in ranking is 4). Designs 4, 5 and 6 are the most cost effective designs for all houses. They are also the least expensive designs. Each design has moderate levels of floor, wall and ceiling insulation (R2.5 wall insulation, R5.0 ceiling insulation and R3.0 and R1.0 floor insulation for the timber-floor and slab-on-ground designs respectively) and windows are reduced in area and double-glazed.

Designs 16 and 21 are the least cost effective for all houses. They are also the two most expensive designs. Each design has windows areas reduced and double-glazed but they also have high levels of floor, wall and ceiling insulation (at least R6.0 floor, wall and ceiling insulation).

Designs 2 and 20 provide the greatest variation in cost effectiveness of all designs. Design 2, a slab-on-ground design, is far less cost effective for the Kingston and Crimson house than it is for Hickman house. One of the design modifications for Design 2 was to tile rather than carpet the living/dining room and bedrooms to utilize the slab's thermal mass. This modification is more cost effective for the Hickman house because unlike the other houses, all of its bedrooms benefit thermally from having a north orientation. The degree to which this is the case is explained further in Section 6.1.3 of Chapter 6.

Design 20 is more cost effective for the Crimson house (6.6 stars) that it is for the Kingston house (6.9 stars). One of the design modifications was to reduce the size of bedroom windows and a south facing living/dining room window. The resultant percentage reduction in glazing area of this modification is greater for the Crimson house than it is for the Kingston house making the reduction in construction cost for the Crimson house greater also. The effect of changing glazing areas to improve thermal performance, and the reasons why the resulting cost effectiveness varies between the houses is discussed in Chapter 6.

5.2.5 Cost versus thermal performance (7-8 stars)

Thermal performance comparisons

Twenty-eight design modifications were made to the Kingston Reference Houses in order to achieve a rating between 7 and 8 stars. (Refer to Table 5.18 below). Figure 5.18 and Figure 5.19 show plots of the star ratings that those designs achieve for each Reference House.

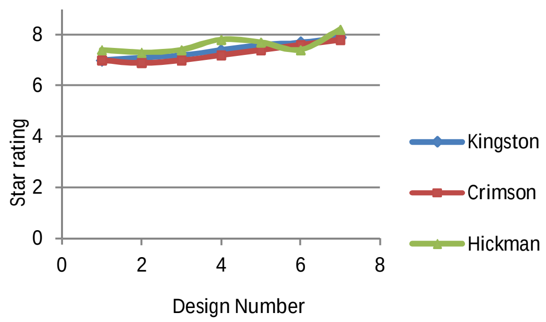


Figure 5.18 - Star rating comparison (timber floor)

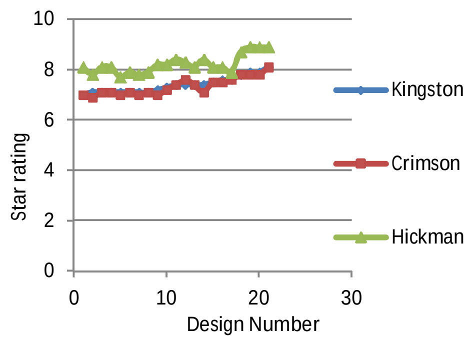


Figure 5.19 - Star rating comparison (slab-on-ground)

For slab-on-ground houses all design modifications provide a higher level of thermal performance for the Hickman house than for the Kingston and Crimson houses. For the timber floor houses all but one of the design modifications provides a higher level of thermal performance for the Hickman house than for the Kingston and Crimson houses. The design modifications to the timber floor and slab-on-ground Kingston and Crimson houses provide a very similar level of thermal performance. In the case of these two houses, rules-of-thumb seem to apply for improving thermal performance to achieve a rating of between 7 and 8 stars. For both the timber floor and slab-on-ground designs, the plot of the Hickman house does not follow the same pattern as the plots for the Kingston and Crimson houses. Reasons for this relate to the Hickman house's design and room layout and are discussed in Section 6.1.3 of Chapter 6.

Table 5.17- Average star rating of design modifications (7-8 star band)

House	Timber floor	Slab-on-ground
Kingston	7.4	7.4
Crimson	7.3	7.3
Hickman	7.6	8.2

Table 5.17 above shows that on average timber floor designs for the Hickman house rate 0.2 stars and 0.3 stars higher than for the timber floor Kingston and Crimson houses respectively. On average, slab-on-ground designs for the Hickman house rate 0.8 stars and 0.9 stars higher than for the slab-on-ground Kingston and Crimson houses respectively.

Kingston (7-8 stars)

Table 5.18 shows all designs resulting from various combinations of changes, and their respective cost to achieve a rating of between 7 and 8 stars. The costs of improvement are relative to the 4-Star Reference Houses.

Table 5.18 – Cost of thermal performance improvements to achieve 7-8 stars (Kingston)

Design (Star Rating, Cost)	**Changes in Building Fabric**	**Design (Star Rating, Cost)**	**Changes in Building Fabric**
1. 7, $205	(W2) (W8) (R1)	**15.** 7.4, $288	(W2) (W11) (R2)
2. 7, $170	(W2) (W4) (C4) (T1)	**16.** 7.4, $148	(W2) (W5) (W4) (C7)
3. 7.1, $158	(W2) (W4) (C4) (T2)	**17.** 7.4, $118	(W2) (C4) (W4) (L1)
4. 7.1, $195	(W2) (W4) (C4) (T1)	**18.** 7.4, $224	(W2) (W4) (C6) (T1)
5. 7.1, $190	(W2) (R4) (W4)	**19.** 7.5, $280	(W2) (R1) (W8) (T1 150mm slab
6. 7.1, $188	(W2) (W4) (C4) (T1) 150 mm slab	**20**. 7.6, $289	(W2) (W8) (C7) (T1)
7. 7.1, $148	(W2) (W4) (R3)	**21.** 7.6, $271	(W2) (W8) (C7) (T2)
8. 7.1, $173	(W2) (W4) (C6)	**22.** 7.6, $190	(W2) (W4,) (R4) (L1)
9. 7.1, $158	(W2) (C8) (W4)	**23.** 7.7, $247	(W2) (R13) (W8) (L1)
10. 7.1, $166	(W2) (C5) (W4)	**24.** 7.8, $179	(W2) (W4) (R3) (T1) (L1)
11. 7.2, $247	(W2) (R14) (W8)	**25.** 7.9, $241	(W2) (W4) (C6) (T1 (W5)
12. 7.2, $120	(W2) (W4) (W7) (T1 (C3)	**26**. 7.9, $334	(W2) (R4) (W8)
13. 7.3, $180	(W2) (R3) (W4) (T1)	**27**. 7.9, $295	(W2) (W4) (C6) (T1 (W12)
14. 7.4, $129	(W2) (W7) (W4) (T1 (C3) (W10)	**28.** 8.1, $378	(W2) (W8) (C6) (T1)

Figure 5.20 shows a plot of the cost of achieving a rating of between 7 and 8 stars, differentiating the timber floor and slab-on-ground designs. The correlation between cost and thermal performance is moderate for the slab-on-ground designs and weak for the timber floor designs, although there are only seven timber floor designs in this star band range.

The most expensive design provides the greatest level of thermal performance improvement. However, the least expensive designs (between $10,000 and $15,000) provide a higher level of thermal performance than 9 other more expensive designs. As was the case for 5-6 and 6-7 star band ratings there can be a considerable difference in cost for designs that achieve the same star rating.

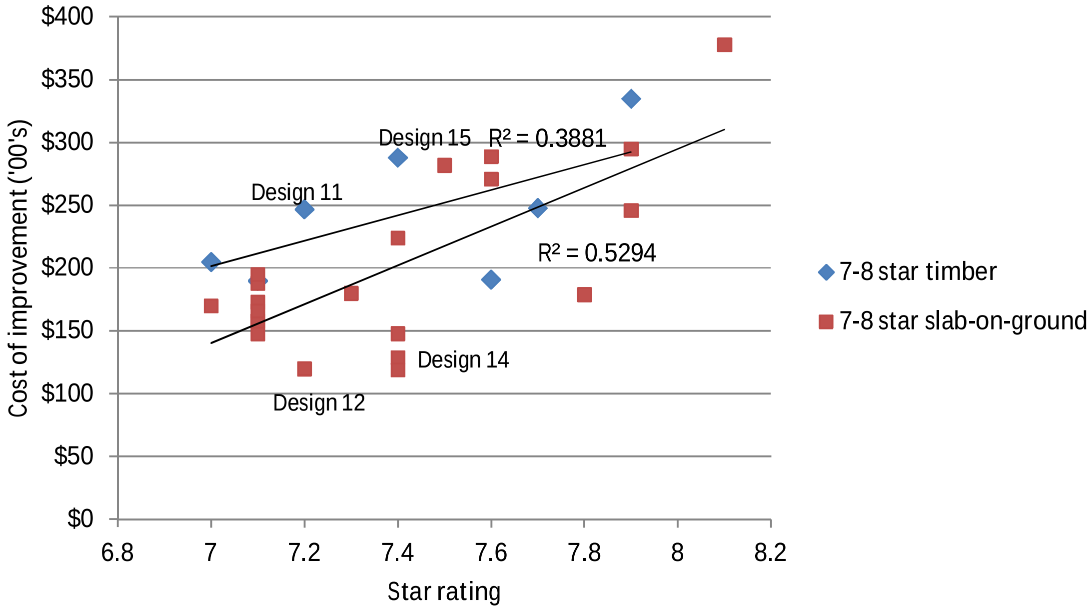


Figure 5.20 – Cost versus thermal performance (Kingston House)

The timber floor Design 11 and the slab-on-ground Design 12 have a 7.2 star rating, though the slab-on-ground design is $12,700 less expensive. The two designs have the same window area and the same moderate levels of wall and ceiling insulation. The difference in cost is attributable to the different window types and the different levels of floor insulation used in the two designs. Combined with other design modifications, the triple-glazed windows used in the timber floor design provide a similar level of thermal performance improvement to the argon-filled double-glazed timber windows used in the slab-on-ground design. However, triple-glazed windows are much more expensive. The timber floor design also requires more floor insulation to achieve the same level of thermal performance as the slab-on-ground design, all else being equal.

Similarly, the difference in cost between the slab-on-ground Design 14 and the timber floor Design 15 is attributable partly to the difference in cost between the windows types. The lower levels of floor, wall and ceiling insulation used in the slab-on-ground design than in the timber floor design also make it less expensive. Comparing the two designs gives an indication of the level of insulation beyond which there are diminishing returns on its effectiveness in improving thermal performance. As a result its cost effectiveness also diminishes.

The windows of the slab-on-ground design are weatherstripped. This provides a low cost method of improving thermal performance. The higher the level of thermal performance, the greater the thermal performance improvement weatherstripping provides.

The average cost of achieving a rating between 7 and 8 stars rating is lower for the slab-on-ground designs than for the timber floor designs (see table 23). However, there are two timber floor designs, which are less expensive than three slab-on-ground designs of the same or lower star rating.

Crimson (7-8 stars)

Table 5.19 shows all designs resulting from various combinations of changes, and their respective cost in achieving a rating of between 7 and 8 stars. The costs of improvement are relative to the 4-star Reference Houses.

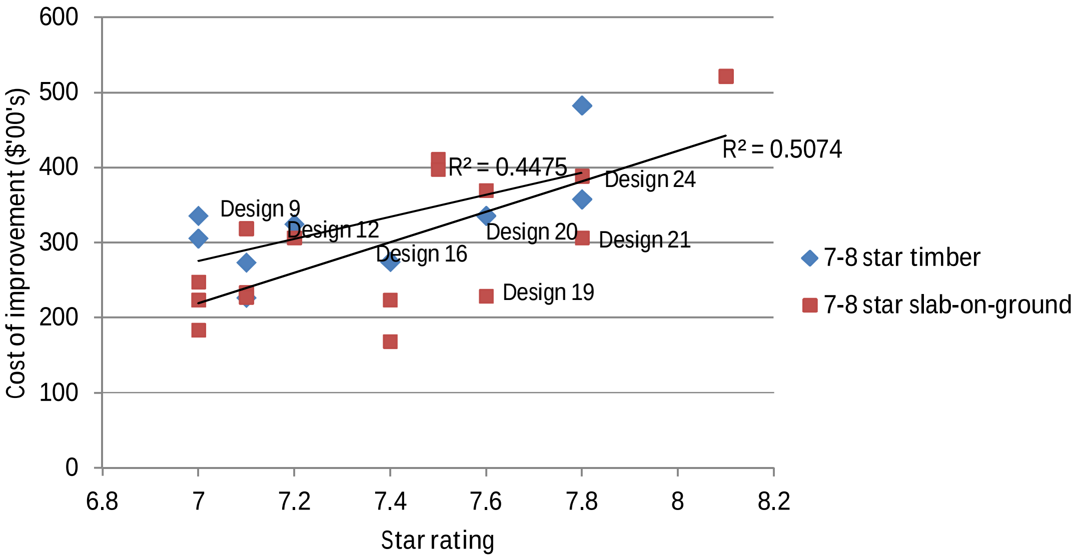


Figure 5.21- Cost versus thermal performance (Crimson House)

Table 5.19 – Cost of thermal performance improvements to achieve 7-8 stars (Crimson)

Design (Star Rating, Cost)	Changes in Building Fabric	Design (Star Rating, Cost)	Changes in Building Fabric
1. 7, $248	(W2)(W4) (C4) (T1)	**14.** 7.4, $169	(W2) (W4) (C4) (L1)
2. 7, $184	(W2) (W3) (R3) + 200mm slab	**15.** 7.4, $224	(W2) (W4) (W7) (T1) (C3) (W10)
3. 7, $224	(C8) (W2) (W4)	**16.** 7.4, $275	(W2) (W4) (R4) (L1)
4. 7, $224	(W2) (W4) (W7) (T1) (C3)	17. 7.5, $411	(W2) (W8) (T1) (C7)
5. 7, $306	(W2) (R11) (W8)	**18.** 7.5, $398	(W2) (W8) (C3)
6. 7, $336	(W2) (R14) (W8)	**19.** 7.6, $229	(W2) (W4) (W5) (R1) (T1) 150mm slab
7. 7.1, $234	(W2) (C6) (W4)	**20.** 7.6, $336	(W2) (R14) (W8) (L1)
8. 7.1, $227	(W2) (W4) (C5)	**21.** 7.8, $307	(W2) (W4) (R3) (T1) 200mm slab, edge insulation (L1)
9. 7.1, $319	(W2) (C5) (T1) (W4) 200mm slab	**22.** 7.8, $358	(W2) (W5) (T1) (C5) (W4) 100mm slab
10. 7.1, $247	(W2) (W4) (T1) (C4) edge insulation	**23.** 7.8 $483	(W2) (W8) (R4)
11. 7.1, $274	(W2) (W4) (T1) (C4) 200mm slab, edge insulation	**24.** 7.8, $389	(W2) (T1) (W4) (W12) (C5) 100mm slab
12. 7.2, $307	(W2) (W4) (R3) (T1) 200mm slab, edge insulation	**25.** 8.1, $522	(W2) (W8) (C6) (T1)
13. 7.2, $325	(W2) (R2) (W11)	**26.** 7.6, $370	(W2) (W8) (T2) (C7)

Figure 5.21 shows a plot of the cost of achieving a rating of between 7 and 8 stars, differentiating the timber floor and slab-on-ground designs. There is a moderate correlation between cost and thermal performance for both floor types. The design with the highest star rating is the most expensive design. However, the least expensive design (14) costs less than approximately 50% of the designs with a lower star rating. Where timber floor and slab-on-ground designs have the same star rating, slab-on-ground designs are less expensive in all cases. The average cost of achieving 7-8 stars is less for the slab-on-ground designs than for the timber-floor designs (see table 5.21).

However, the timber floor Design 16 is less expensive than two slab-on-ground designs, 9 and 12, both of which have a lower star rating. All designs have the same glazing area and the same windows were double-glazed. The timber floor design has significantly higher levels of floor insulation than the slab-on -ground designs. The reason the timber floor design is less expensive is because downlights were removed and the external wall colour was changed from light to dark. These are no-cost changes that increased thermal performance by 0.6 stars. In contrast, changes were made to the slab-on-ground designs aimed at utilizing the slab's thermal mass. The slab-on-ground designs have tiling in lieu of carpet and Design 9 also had its slab thickness doubled. These are expensive changes, which provide minimal thermal performance improvement.

There are slab-on-ground designs that have the same star rating but differ in cost somewhat, for example Designs 21 and 24. Both designs have the same window area and the same windows double-glazed, the same slab thickness, and tiles in lieu of carpet. The less expensive design has no downlights whereas the more expensive design has higher levels of wall and ceiling insulation, as well as thermally broken aluminium windows. This shows that removing downlights can provide the same level of thermal performance improvement as the combined change of higher levels of wall and ceiling insulation and thermally broken aluminum windows.

Designs 19 and 20 have the same glazing area and the same moderate levels of floor, wall and ceiling insulation. However, the less expensive Design 19 has timber-framed double-glazed windows, a thicker slab, and tiles in lieu of carpet in the bedrooms, whereas the more expensive Design 20 has triple-glazing. The thermal performance improvement that triple-glazing provides is the same as the timber double-glazed, thicker slab and tiled bedrooms provides for the less expensive design.

Hickman (7-8 stars)

Table 5.20 shows all designs resulting from various combinations of changes, and their respective cost to achieve rating between a 7 and 8 stars. The costs of improvement are relative to the 4-star Reference Houses.

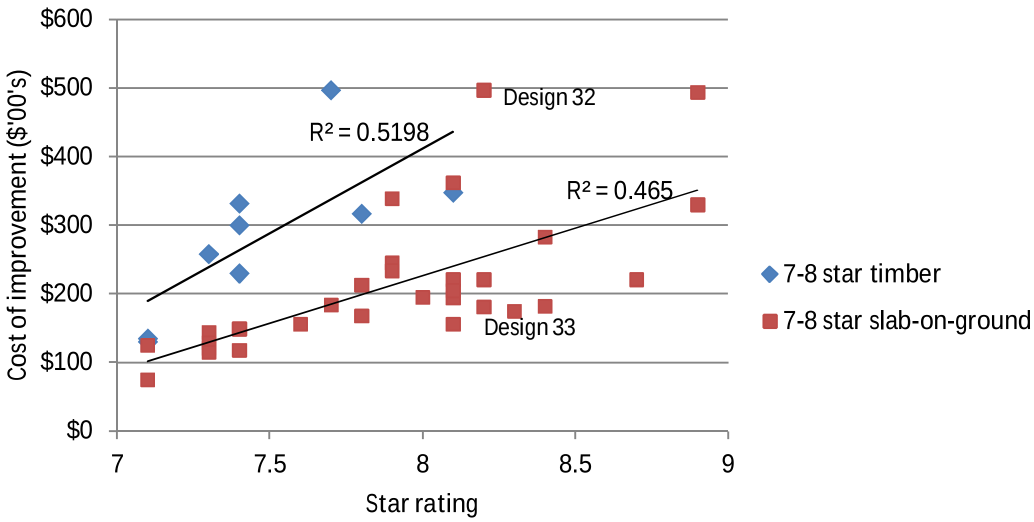


Figure 5.22 - Cost versus thermal performance (Hickman)

Table 5.20 – Cost of thermal performance improvements to achieve 7-8 stars (Hickman)

Design (Star Rating, Cost)	**Changes in building fabric**	**Design (Star Rating, Cost)**	**Changes in building fabric**
1. 7.1, $130	(W2) (W4) (R10)	**22.** 7.8, $168	(W2) (W4) (C4) (T2)
2. 7.1, $75	(W2) (W4) (C1)	**23.** 7.9, $234	(W2) (W4) (C5)
3. 7.1, $125	(W2) (W4) (C7) (T2)	**24.** 7.9, $340	(W2) (W8) (T2) (C7)
4. 7.1, $135	(W2) (W4) (W5) (R1)	**25.** 8.0, $195	(W2) (W4) (C4) (T1) edge insulation
5. 7.3, $258	(W1) (W4) (R4)	**26.** 8.1, $348	(W2) (W8) (T1) (C7)
6. 7.3, $144	(W2) (W4) (C7) (T1)	**27.** 8.1, $221	(W2) (W4) (R3) (T1) 200mm slab, edge insulation
7. 7.3, $121	(W1) (W4) (T1) (C7)	**28.** 8.1, $194	(W2) (W4) (C4) (T1)
8. 7.3, $129	(W2) (W4) (R1) (T1)	**29.** 8.1, $156	(W2) (W4) (C4) (L1)
9. 7.3, $114	(W1) (W4) (C2) edge insulation	**30.** 8.1, $205	(W2) (W4) (C4) (T1) edge insulation and 150mm slab
10. 7.4, $300	(W2) (W11) (R1)	**31.** 8.1, $362	(W2) (T1) (C7) (W8)
11. 7.4, $229	(W2) (W4) (R11) (L1)	**32.** 8.2, $497	(W2) (W8) (R4) (L1)
12. 7.4, $332	(W2) (W8) (R14) (L1)	**33.** 8.2, $181	(W2) (W4) (W5) (R1) (T1)
13. 7.4, $118	(W2) (W4) (T1) (R1)	**34.** 8.2, $221	(W2) (W4) (T1) (R3) edge insulation and 200mm slab
14. 7.4, $149	(W2) (W4) (C2)	**35.** 8.3, $174	(W2) (W4) (W5) (T1) (R1)
15. 7.4, $149	(W2) (W4) (C2) edge insulation	**36.** 8.4, $282	(W2) (W4) (C6) (T1)
16. 7.6, $156	(W2) (W4) (C4)	**37.** 8.4, $182	(W2) (W4) (W7) (W5) (W10 (R1) (T1)
17. 7.7, $184	(W2) (W4) (R3) 200mm slab	**38.** 8.9, $330	(W2) (W4) (C6) (T1) (W5)
18. 7.7, $497	(W2) (L1) (W8) (R4)	**39.** 8.7, $221	(W2) (W4) (R3) (T1) (L1) 200mm slab, edge insulation
19. 7.8, $317	(W2) (W11) (R4)	**40.** 8.9, $494	(W2) (W8) (C8) (T1)
20. 7.8, $213	(W2) (W4) (C8)		
21. 7.9, $245	(W2) (W4) (C6)		

Figure 5.22 above shows a plot of the cost of achieving between a 7 and 8 star rating, differentiating the timber floor and slab-on-ground designs. The correlation between cost and thermal performance is moderate for both floor types, although it is stronger for the timber floor design. There are considerably more slab-on-ground designs than timber floor designs in this star band range for the Hickman house than for the Kingston and Crimson houses. This is because slab-on-ground designs that achieve a rating of between 6 and 7 stars for the Kingston and Crimson houses are achieving 7-8 stars for the Hickman house. Over 50% of the slab-on-ground designs have a star rating that exceeds 8 stars.

Approximately 50% of the thermal performance improvements for the slab-on-ground designs cost less than $20,000 whereas all but one of the timber floor design costs more than $20,000. Table 5.21 shows that the average cost of achieving a rating of between 7 and 8 stars is less for the slab-on-ground houses than for the timber-floor houses.

There is only one case where a timber floor design is less expensive than a slab-on-ground design with the same or lower star rating. However, there are some slab-on-ground designs that are less expensive than others with the same or lower star rating. For example Designs 32 and 33 both have an 8.2 star rating but the latter is approximately $30,000 more expensive. The designs have the same window area and the same windows are double-glazed. However, the less expensive design has timber in lieu of aluminium windows and much lower levels of insulation. The other design differences are that the less expensive design has tiles in lieu of carpet whereas the more expensive design had the downlights removed. The extra cost of the more expensive design's higher insulation levels far exceeds the extra cost of the less expensive design's timber windows and tiling in lieu of carpet. Despite the cost disparity of these design differences they achieve the same level of thermal performance improvement.

7-8 star summary

Table 5.21 below shows that for each of the three houses, on average it costs less for the slab-on-ground designs to achieve 7-8 stars than it does for the timber floor houses.

Table 5.21 – Average increase in construction cost (7-8 stars)

	Average cost increase (% and $/m2)	
House	**Timber floor**	**Slab-on-ground**
Kingston	18 % ($243/m2)	13 % ($184/m2)
Crimson	14 % ($185/m2)	12 % ($168/m2)
Hickman	17 %($223/m2)	13 % ($177/m2)

The difference in cost increase between the floor types is greatest for the Hickman house, which has the highest percentage cost increase for the timber floor designs and the lowest percentage cost increase for the slab-on-ground designs. It has the highest combined average percentage increase of the three houses. However, these results need to be put into context. The average star rating of designs of both floor types is significantly higher for the Hickman house than it is for the Kingston and Crimson houses. Table 5.22 summarises the relationship between the cost of a thermal performance improvement for all houses and savings in CO_2-e (or increase in thermal performance) it provides.

Cost versus space heating/cooling CO_2-emissions (7-8 stars)

Figure 5.23 shows the cost of thermal performance changes versus the annual theoretical savings in space-conditioning CO_{2-} emissions they provide compared to the Kingston, Crimson and Hickman 4-star Reference Houses, respectively.

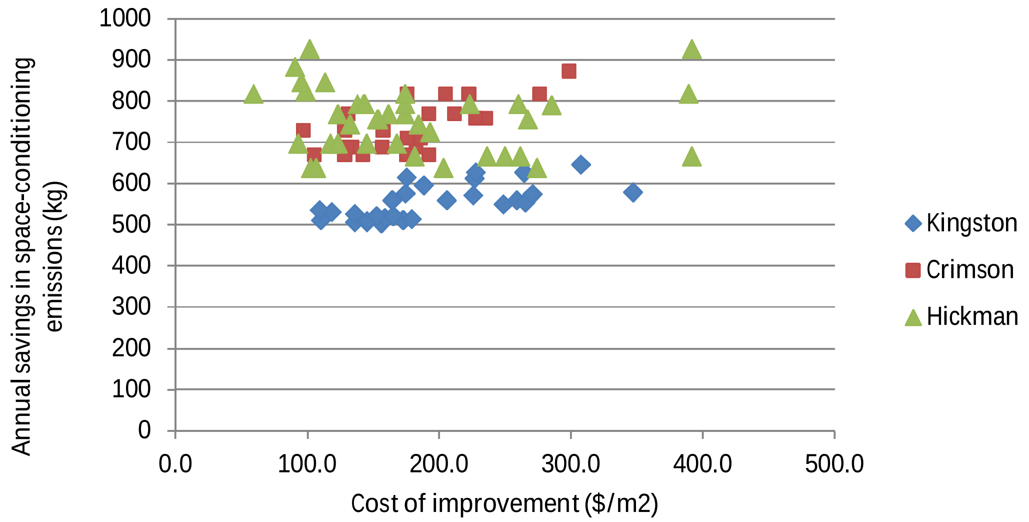


Figure 5.23 – Comparison of cost versus annual savings in space-conditioning emissions

Table 5.22 shows that on average, $1,000 spent on thermal performance improvements to achieve 7-8 stars provides the greatest saving in CO2-e for the Hickman house at 32 kg per annum. Compared to the 6-7 star band, it costs more for each house to save a kg of CO_2-e.

Table 5.22 – Average cost of achieving 7-8 stars and the resultant savings in CO_2-emissions

House	Average cost	Average CO_2-e saved (kg) (per annum)	$1000/CO2-e saved (per annum)
Kingston	$21,340 ($194/m2)	555kg	26kg
Crimson	$30,798 ($174/m2)	733kg	24kg
Hickman	$22,860 ($180/m2)	753kg	32kg

Cost effectiveness in reducing space-conditioning CO_2 emissions (7-8 stars)

Figure 5.24 shows the cost effectiveness rankings of thermal performance improvements for the three houses. For the purposes of calculating cost effectiveness, as for the 5-6, and 6-7 star houses, the design modifications are those that achieve between a 7 and 8 star rating for the Kingston houses.

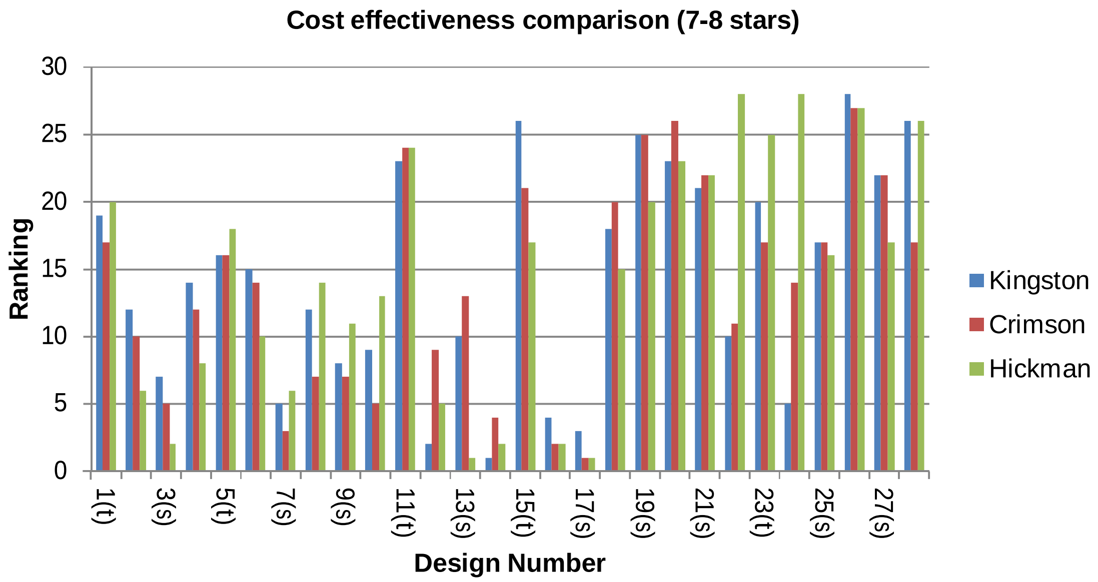


Figure 5.24 – Cost effectiveness of design modifications in saving space conditioning CO_2-e

Compared to 5-6 and 6-7 star bands, there is a greater variability in rankings that a certain design achieves across the 3 houses. The average range in ranking is 4.5. Reasons for the variability in rankings between houses as thermal performance increases are discussed in Chapter 6. None of the designs in this star band range provide the same ranking for all three houses. Designs 14, 16 and 17 are the most cost effective for all three houses as well as being the three least expensive designs. Each design is slab-on-ground and has reduced window areas, which were double-glazed. Designs 14 and 16 have moderate levels of floor, wall and ceiling insulation and timber windows. The higher the star rating a design has, the more cost effective installing timber windows becomes in further improving its thermal performance. Design 17 has moderate levels of floor insulation and high levels of wall and ceiling insulation and no downlights. As previously mentioned removing downlights is a cost effective measure in improving thermal performance.

Designs 26 and 28 are amongst the least cost effective designs for all three houses because of their triple-glazing. Triple-glazing is expensive and provides very little thermal performance improvement over double-glazing. The difference in ranking between the highest and lowest ranking for Designs 8, 12, 15, 22 and 24 is at least seven.

5.2.6 Summary of Cost Effectiveness 4-8 stars

Previous sections examined the cost effectiveness of designs within single star band ranges. Figure 5.25 below shows the cost effectiveness of all sixty-six designs that achieved a star rating between 5 and 8 stars for the Kingston house (noting that these same designs in some cases achieved a star rating lower than 5 or higher than 8 for the Crimson or Hickman houses.). While for each house the correlation between cost-effectiveness and thermal performance is not particularly strong, in general a design's cost effectiveness decreases as its star rating increases. A vast majority of designs with a cost effectiveness ranking of 10 or less have a star rating of 6 or less.

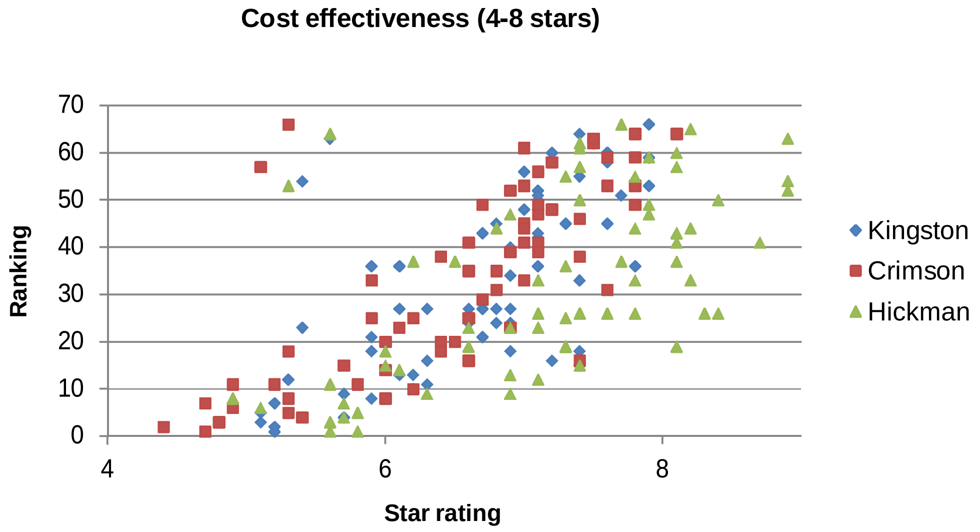


Figure 5.25 – Cost effectiveness in saving space-conditioning emissions

5.3 EMBODIED ENERGY VERSUS THERMAL PERFORMANCE

This section examines the relationship between embodied energy and incremental improvements in the thermal performance of houses. The aim is to identify the influence that embodied energy has on the cost effectiveness of thermal performance improvements in saving CO_2-e.

Embodied energy versus thermal performance (4- 8 stars)

Figures 5.26, 5.27 and 5.28 show plots of the embodied energy versus thermal performance of the various design modifications aimed at improving the thermal performance, up to 8 stars, of the 4-Star Kingston, Crimson, and Hickman Reference Houses, respectively. The increase in embodied energy is relative to the embodied energy of the 4-Star Reference Houses. The plots do not differentiate between timber floor and slab-on-ground designs.

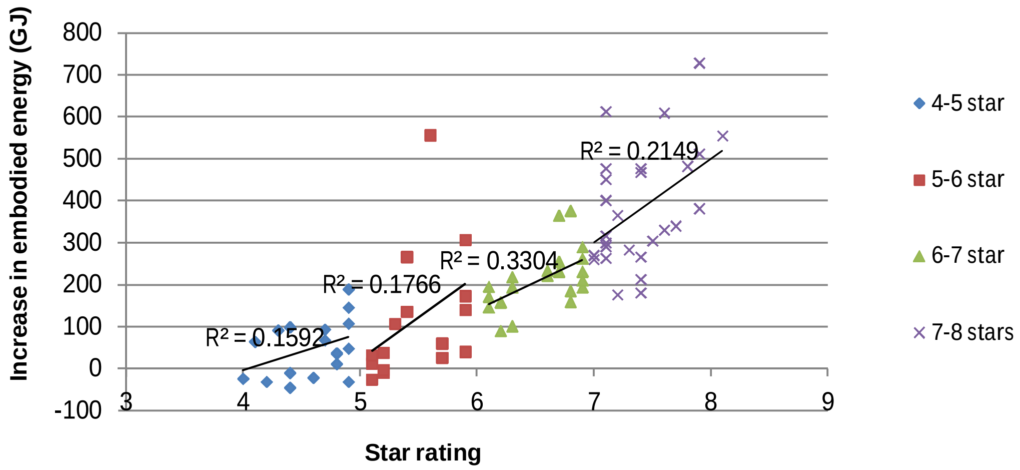


Figure 5.26 – Increase in embodied energy versus star rating (Kingston House)

Kingston House

Figure 5.26 shows that while generally increasing the thermal performance of the house results in its embodied energy increasing as well, it is not always the case. About 30% of the 4-5 star designs, and two 5-6 star designs, have a lower embodied energy than the 4-star Reference Houses. Furthermore, there are 7-8 star designs, which have a lower embodied energy than 5-6 star and 6-7 star designs. The correlation between embodied energy and thermal performance strengthens as thermal performance increases from the 4-5 star band range up to the 6-7 star band range. It then weakens in the 7-8 star band range.

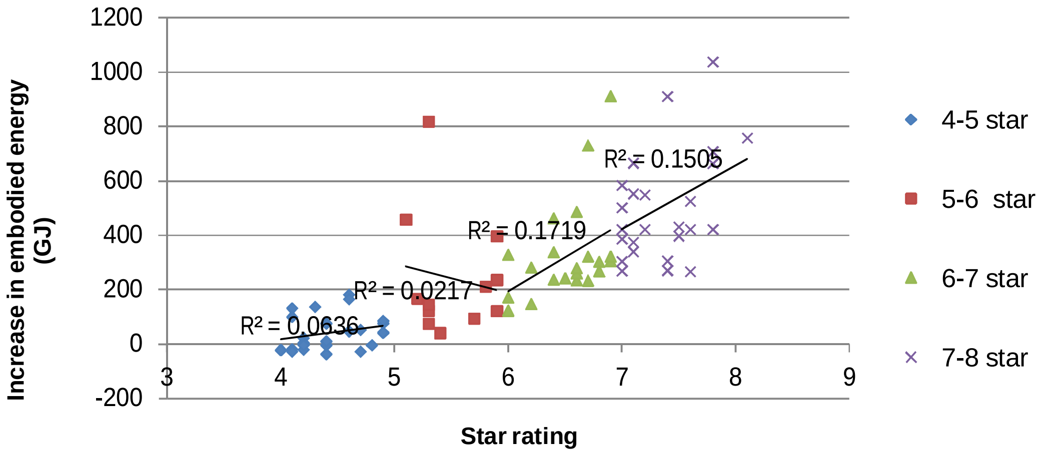


Figure 5.27 – Increase in embodied energy versus star rating (Crimson House)

Crimson

Figure 5.27 shows that as for the Kingston house, incrementally improving thermal performance does not necessarily result in incremental increases in embodied energy. Many of the 4-5 star designs have a lower embodied energy than the 4-Star Reference Houses. There are 5-6 and 6-7 star designs with lower embodied energy than 4-5 designs. Unlike for the Kingston and Hickman houses, the correlation between embodied energy and thermal performance does not strengthen as thermal performance increases from the 4-5 star band range to the 6-7 star band range.

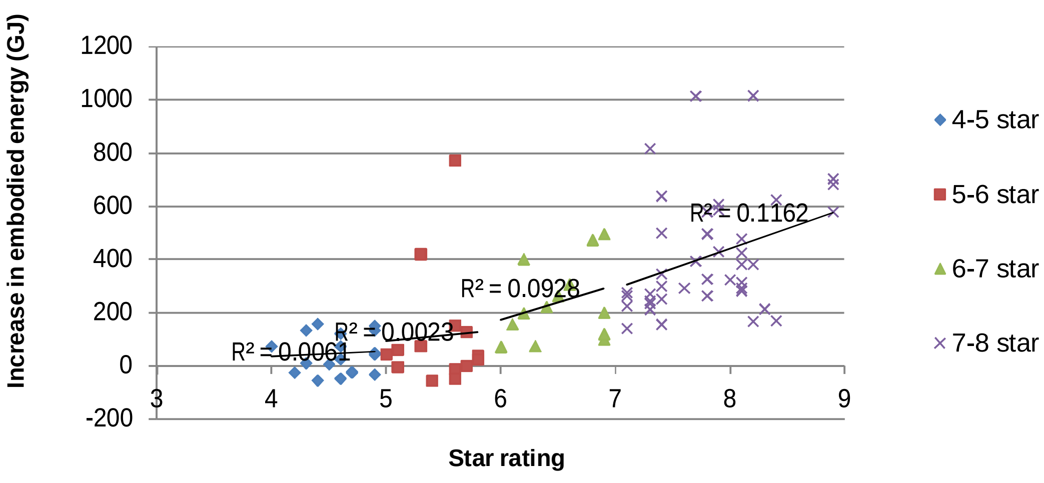


Figure 5.28 – Increase in embodied energy versus star rating (Hickman House)

Hickman

Figure 5.28 shows that as for the Kingston and Crimson houses incrementally improving thermal performance does not necessarily result in incremental increases in embodied energy. While many of the 4-5 and 5-6 star designs have a lower embodied energy than the 4-Star Reference Houses, designs with a 6 star rating or more have a higher embodied energy than the Reference houses. There are 5-6 and 6-7 designs, which have a lower embodied energy than 4-5 designs, and there are 7-8 star designs with lower embodied energy than 5-6 and 6-7 star designs. Generally the correlation between embodied energy and thermal performance strengthens as thermal performance increases (represented by higher star ratings).

Increase in embodied energy versus thermal performance (5-6 stars)

The following part of this section examines each house in each star band range, differentiating between the floor types. The aim is to establish the nature of the relationship between increases in thermal performance and embodied energy. Design differences that may contribute to differences in embodied energy are discussed in Chapter 6.

Kingston

Figure 5.29 shows that the correlation between thermal performance and increase in embodied energy for the timber floor and slab-on-ground designs is weak and moderate respectively. Generally, however, the higher the star rating of a design, the greater its increase in embodied energy.

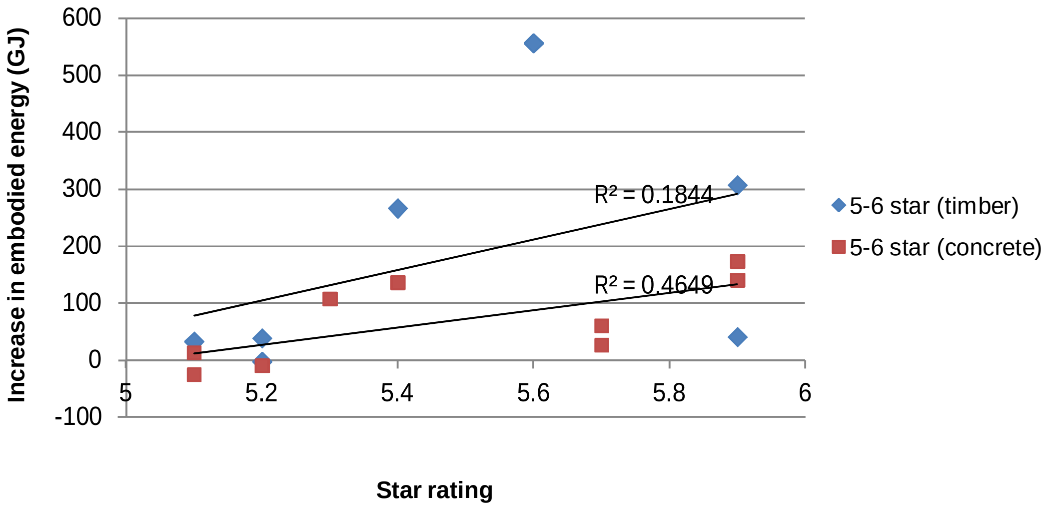


Figure 5.29 – Increase in embodied energy versus thermal performance (Kingston House)

The average increase in embodied energy for timber-floor and slab-on-ground designs is 11 % and 5 % respectively. Although, of the four designs with the highest star rating (5.9), a timber floor design has the lowest increase in embodied energy.

Crimson house

Figure 5.30 shows that the correlation between increase in embodied energy and thermal performance for the timber floor designs is very weak, and negatively correlated for the slab-on-ground designs. For the slab-on-ground designs, as star ratings increase the increase in embodied energy decreases. For the timber-floor houses, the 5.1 star design and one of the 5.9 star designs, have a higher embodied energy than all other designs.

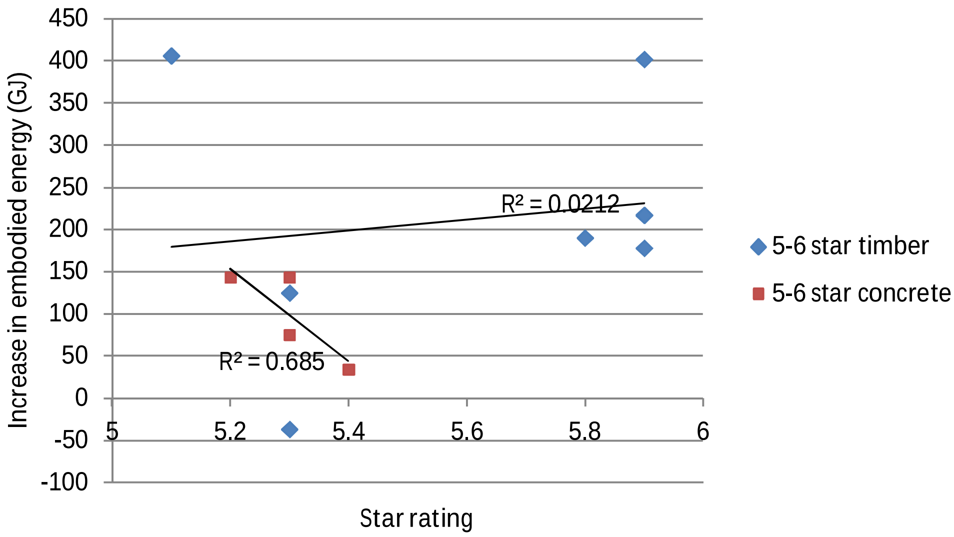


Figure 5.30 – Embodied energy versus thermal performance (Crimson House)

The average increase in embodied energy is greater for timber-floor houses than it is for slab-on-ground houses (see Table 5.23 below). However, the increase in embodied energy of the 5.7 timber floor house is lower than the increase in embodied energy of two slab-on-ground designs with a lower star rating.

Hickman

Figure 5.31 shows that as for the Kingston and Crimson houses, the correlation between thermal performance and increase in embodied energy for both floor types is weak. Table 5.23 below shows that for the Hickman house the average increase in embodied energy for timber-floor designs is significantly higher than it is for slab-on-ground designs.

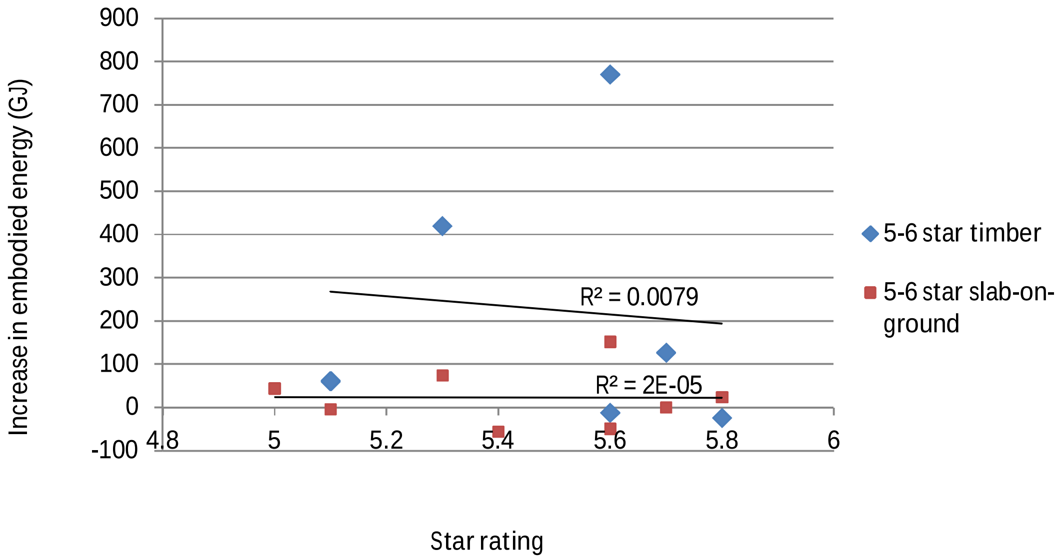


Figure 5.31 – Embodied energy versus thermal performance (Hickman House)

Summary of 5-6 star band

Table 5.23 below shows that for all three houses, the average increase in embodied energy for the timber-floor houses ranges from 7% for the Crimson house to 11% for the Kingston house. For all three houses, the average increase in embodied energy of the slab-on-ground designs for all three houses is considerably lower, at around 1-4 %.

Table 5.23 –Average increase in embodied energy for 5-6 star houses

House	Timber floor	Slab-on-ground
Kingston	11%	5%
Crimson	7%	4%
Hickman	12%	1%

Increase in embodied energy versus thermal performance (6-7 stars)

Kingston House

Figure 5.32 shows that for both floor types, the correlation between thermal performance and increase in embodied energy is moderate. Generally, however, the higher the star rating of a design, the greater its increase in embodied energy.

The average increase in embodied energy for the timber-floor design and slab-on-ground designs is around 17 % and 12 % respectively (see table 5.24). (The difference between the floor types is much lower than it is for the 5-6 star designs). Of the designs with the highest star rating (6.9), a timber floor design has the lowest increase in embodied energy.

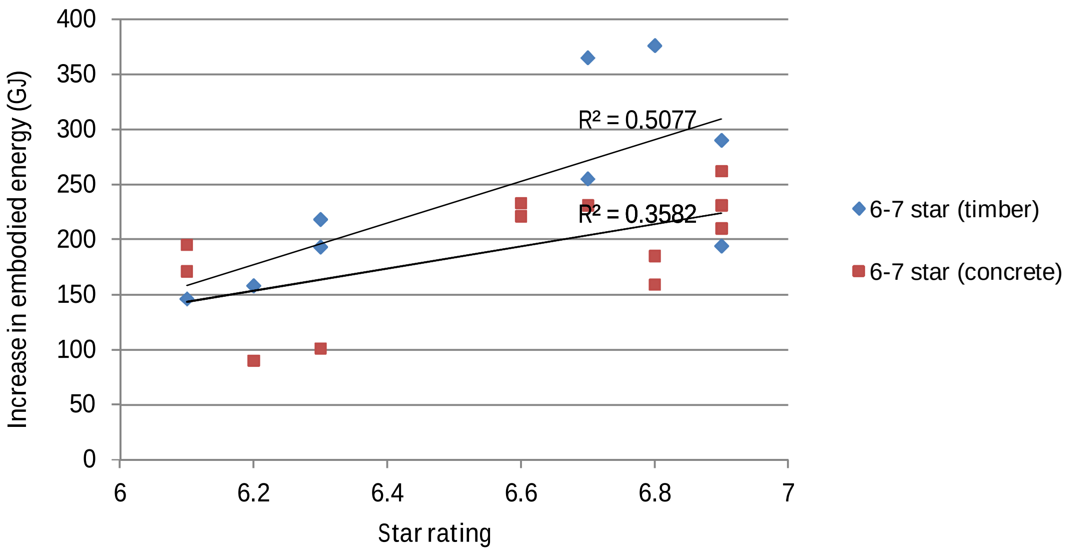


Figure 5.32 – Embodied energy versus thermal performance (Kingston)

Crimson

Figure 5.33 below shows that compared to the 5-6 star Crimson house designs, the correlation between thermal performance and an increase in embodied energy has strengthened. The average increase in embodied energy is higher for the timber-floor designs (14 %) than it is for the slab-on-ground designs (11 %) (see table 5.24 below).

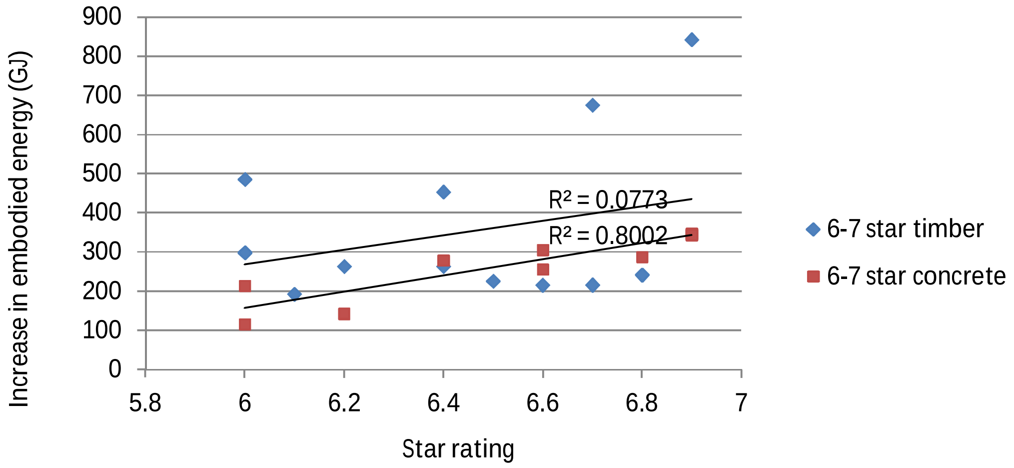


Figure 5.33 – Embodied energy versus thermal performance (Crimson)

Hickman House

Figure 5.34 below shows that the correlation between thermal performance and increase in embodied energy is considerably stronger for the timber-floor designs than it is for the slab-on-ground designs. The average increase in embodied energy is greater for the timber-floor designs than the slab-on-ground designs (see Table 5.24 below).

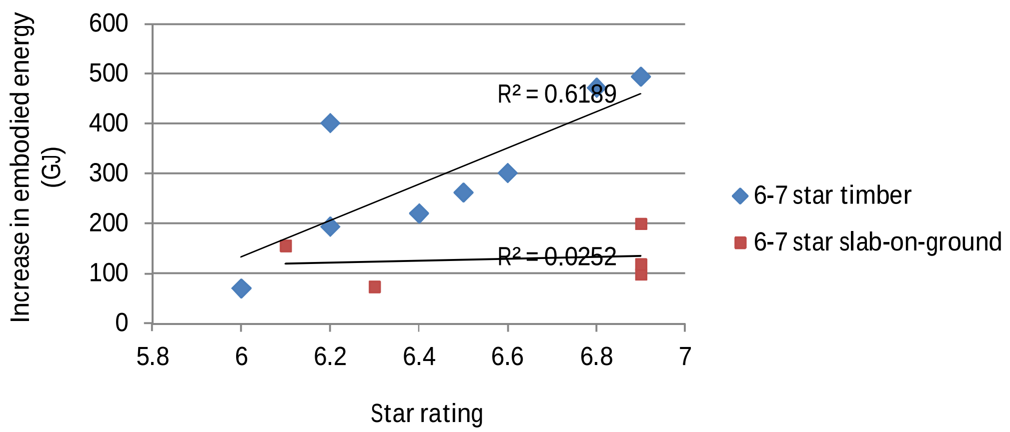


Figure 5.34 – Embodied energy versus thermal performance (Hickman)

Summary of 6-7 star band

Table 5.24 below shows that the average increase in embodied energy for the timber-floor houses ranges from 14% (Crimson) to 17% (Kingston). The average increase in embodied energy of the slab-on-ground designs is lower than the increase in embodied energy of timber floor designs for all three houses, ranging from 7% (Hickman) to 12% (Kingston).

Table 5.24 – Average increase in embodied energy 6-7 star houses

House	Timber floor	Slab-on-ground
Kingston	17%	12%
Crimson	14%	11%
Hickman	16%	7%

Embodied energy versus thermal performance (7-8 stars)

Kingston

Figure 5.35 shows that for both floor types, the correlation between embodied energy and thermal performance remains weak for the 7-8 star designs. The average increase in embodied energy is higher for the timber-floor designs than it is for the slab-on-ground designs (see Table 5.25 below). There is only one timber-floor design (a 7 star design) with a lower increase in embodied energy than a slab-on-ground design with the same or lower star rating.

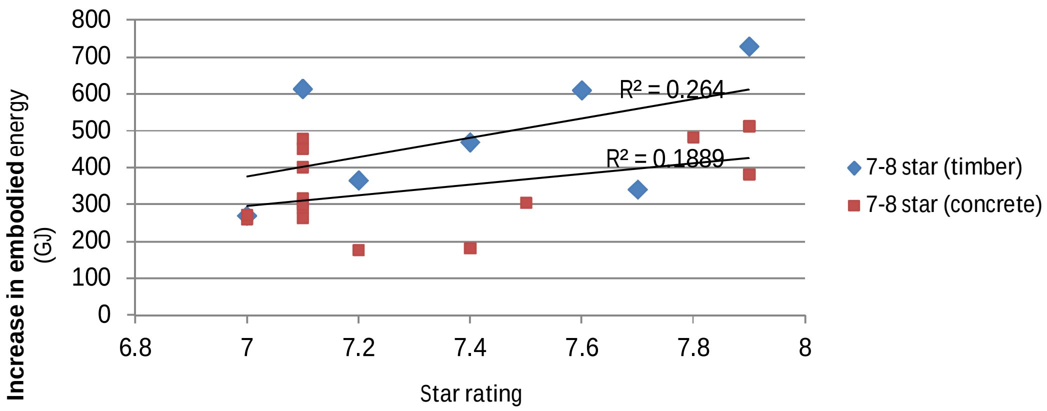


Figure 5.35 – Embodied energy versus thermal performance (Kingston)

Crimson

Figure 5.36 shows a moderate and a weak correlation between thermal performance and increase in embodied energy for the timber-floor and slab-on-ground designs, respectively. While the average increase in embodied energy is greater for the timber-floor designs than it is for the slab-on-ground designs (see Table 5.25 below), there are several timber-floor designs that have a lower increase in embodied energy than slab-on-ground designs of the same or lower star rating.

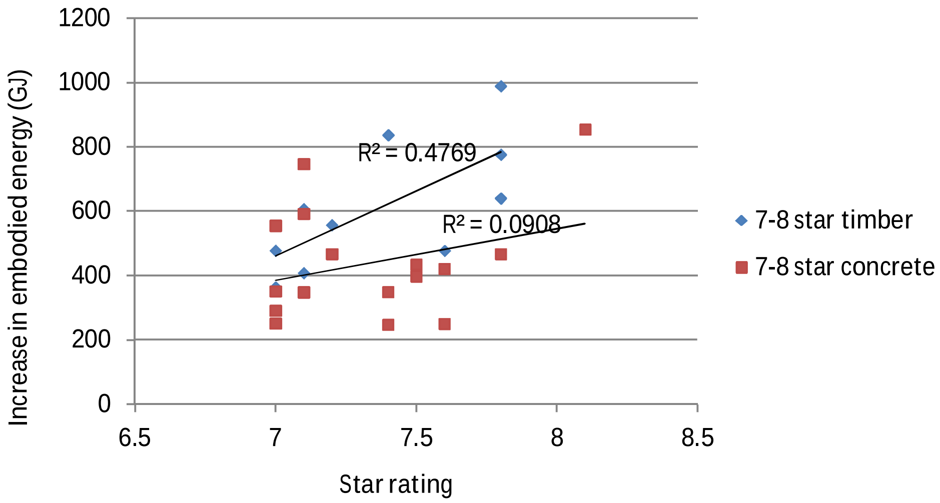


Figure 5.36 – Embodied energy versus thermal performance (Crimson)

Hickman

Figure 5.37 shows that the correlation between thermal performance and increase in embodied energy is weak and moderate for timber floor and slab-on-ground designs, respectively. The average increase in embodied energy is greater for the timber-floor designs than it is for slab-on-ground designs (see table 5.25 below). Apart from two designs, all slab-on-ground designs have a lower increase in embodied energy than timber-floor designs with the same or higher star rating.

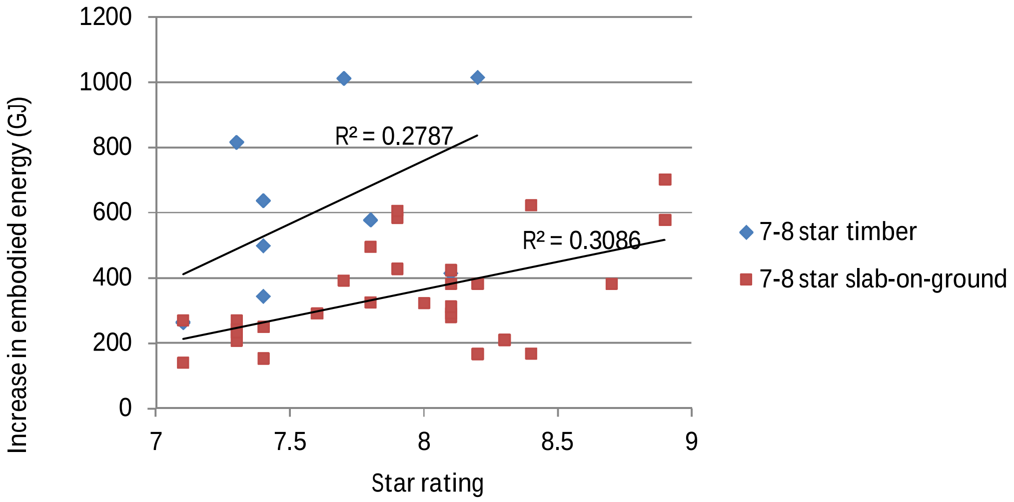


Figure 5.37 – Embodied energy versus thermal performance (Hickman)

Summary of 7-8 star band

Table 5.25 below shows, the average increase in embodied energy is greater for the timber-floor houses than the slab-on-ground houses. In the case of the Hickman house, the average increase in embodied energy is significantly greater at 12 percentage points.

Table 5.25 – Average increase in embodied energy for 7-8 star houses

House	Timber floor	Slab-on-ground
Kingston	31%	23%
Crimson	25%	18%
Hickman	31%	19%

This section sought to identify the influence that embodied energy has on the cost effectiveness of thermal performance improvements in saving CO_2-e. That embodied energy increases with thermal performance means that the cost effectiveness of measures in saving CO_2-e decreases. However, it was shown that the correlation between thermal performance and increases in embodied energy is not strong for either floor type in any of the star band ranges, suggesting that the materials and methods used to improve thermal performance will affect the cost effectiveness of the measure in saving CO_2-e.

5.4 CAPITAL COST VERSUS EMBODIED ENERGY

This thesis examines the cost effectiveness of thermal performance measures in reducing CO_2 emissions, taking into account the embodied emissions as well as the reduction in space-conditioning emissions that they provide. Section 5.2 explored the relationship between capital cost and increase in thermal performance (or reduction in space-conditioning emissions), while section 5.3 looked at the relationship between embodied energy and thermal performance. This section will examine the relationship between the capital cost of the thermal performance measures and the resulting change in the embodied emissions of designs.

Embodied energy versus cost (5-6 stars)

Kingston house

Figure 5.38 below shows that there is a very strong correlation between cost and embodied energy for both timber and slab-on-ground designs. The designs with the highest and lowest increase in embodied energy are the most expensive and least expensive designs respectively.

Design 1has the same window area as Design 11 but the living/dining room windows are double-glazed. No other design modifications were made. While the double-glazing of Design 1 costs more than the extra insulation of Design 11, it has a lower embodied energy. Designs 3 and 5 had floor insulation added and their wall insulation increased modestly (to R2.5). Both designs had downlights removed and the external wall colour was changed from light to dark. It was assumed that the embodied energy did not change as a result of this modification. The cost of reducing window size and increasing insulation levels for Design 11 is less than adding floor insulation and increasing the wall insulation of Designs 3 and 5. However, the net increase in embodied energy that results from the extra ceiling insulation and reducing window sizes is greater than the increase in embodied energy that results from improving the thermal performance of Design 3 and 5. The higher cost but lower embodied energy of Design 14 as compared to Design 11 is attributable to the timber in lieu of aluminium windows of Design 14. While timber windows cost more than aluminium ones, they have a lower embodied energy.

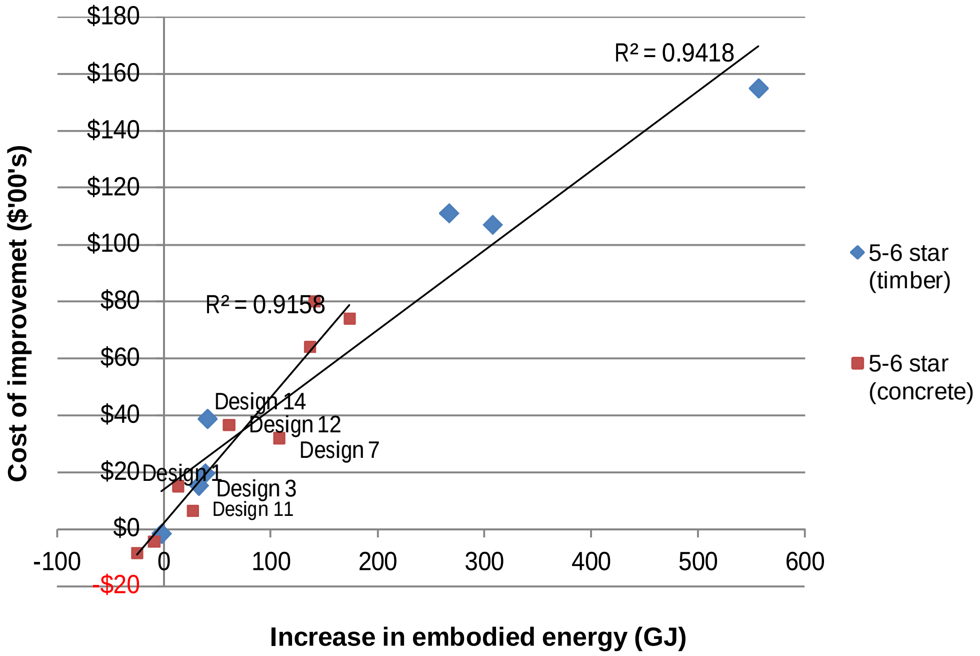


Figure 5.38 – Increase in embodied energy versus cost (Kingston)

There are designs with a similar increase in embodied energy but which differ significantly in cost, and cases where the reverse is true. For example Designs 3 and 12 have a similar embodied energy but Design 12 is more expensive because it has double-glazed windows. The additional embodied energy of double-glazing over single glazing was more than offset by reducing the size of the windows, but this does not offset the additional cost.

Likewise, the costs of Design 7 and 12 are similar. However, Design 12 has a lower embodied energy. While the two designs have the same levels of floor and ceiling insulation, Design 7 has R3 under-slab insulation whereas the windows of Design 12 were reduced in size and double-glazed. Therefore, in this particular case, reducing window sizes and double-glazing is very similar in cost to installing R3.0 under-slab insulation.

Crimson

Figure 5.39 shows that there is a strong correlation between cost and embodied energy for the both the timber floor and slab-on-ground designs. It should be noted however that there are fewer timber-floored designs than slab-on-ground designs.

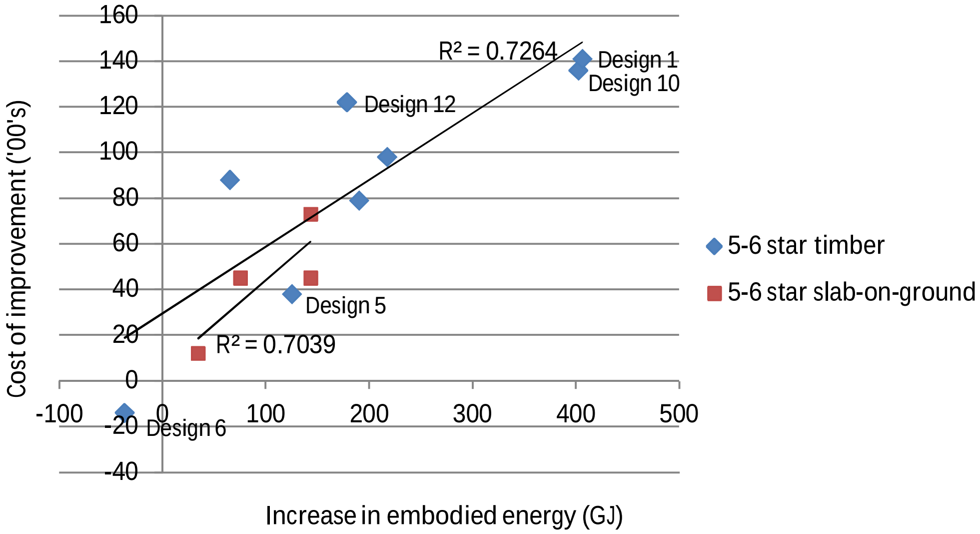


Figure 5.39 – Increase in embodied energy versus cost (Crimson)

Designs 1 and 10 have the highest embodied energy and are the most expensive. For both designs wall and ceiling insulation levels were increased significantly (to R6.0 and R8.0) and high levels of floor insulation added (R6.0). Design 6 is the least expensive design (negative cost) which also results in a decrease in embodied energy. The only design change made to improve thermal performance was to decrease its window area.

As for the Kingston house, there are designs with a similar embodied energy but which differ in cost. For example, Designs 5 and 12. The two designs have the same windows area, and the same level of wall and ceiling insulation. However, Design 12 has timber-framed windows in lieu of aluminium, which are more expensive but have a lower embodied energy. In this case, switching the windows from aluminium to timber windows improved the design's thermal performance by 0.6 stars.

Hickman

Figure 5.40 shows that cost and increase in embodied energy are strongly correlated for the timber floor and slab-on-ground designs. Design 8 is the most expensive design and has the highest embodied energy. It has high levels of floor, wall and ceiling insulation added. Design 6 is the least expensive design and has the lowest embodied energy, the result of reducing the size of living/dining and bedroom windows. This was the only thermal performance modification made.

However, there are designs with the same or very similar embodied energy that differ in cost, and designs where the reverse is true. For example, Design 1 and 14 have a similar embodied energy but design 14 is less expensive (and has a 0.8 higher star rating). Design 1 had R1 under-slab insulation added whereas Design 14 had window areas reduced and its wall and ceiling insulation levels increased modestly (to R2.5 and R5.0 respectively). Under-slab polystyrene insulation has a higher embodied energy than bulk insulation and, in this particular case, the R1 under-slab insulation results in a similar net increase in embodied energy as reducing window sizes and increasing wall and ceiling insulation levels.

The slab-on-ground designs 1 and 12 are very similar in cost but Design 12 has a lower embodied energy. Design 12 had the living/dining and bedroom window reduced and double-glazed whereas Design 1 had R1.0 slab insulation added. The slab insulation has a higher embodied energy than the net increase in embodied energy that results from reducing and double-glazing windows. Interestingly, the window changes result in a 0.7 higher star rating than adding floor insulation.

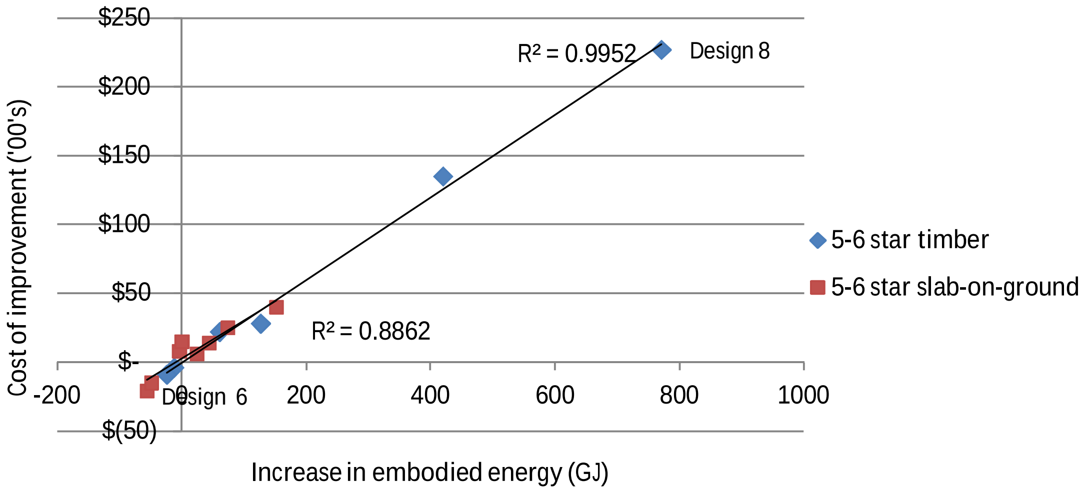


Figure 5.40 – Increase in embodied energy versus cost (Hickman)

Cost effectiveness of thermal performance improvements in reducing embodied emissions

Figure 5.41 below shows the cost effectiveness ranking of thermal performance improvements in minimising the net increase in embodied CO_2-e for the three houses. In this case, cost effectiveness is the ratio of the cost of the thermal performance improvement to the increase in embodied emissions (annualized based on a 25-year life). The higher the ratio, the more cost effective the thermal performance improvement in minimising embodied CO_2-e. For example if a $100 is spent on a thermal performance improvement, which results in a 1000kg increase of embodied emissions, the cost effective ratio is 0.1. On the other hand if a different thermal performance improvement that also costs $100 results in an increase of 500g of embodied emissions, the cost effective ratio 0.2. The latter example with the higher ratio results in fewer embodied emissions and is therefore considered the more cost effective.

For the purposes of calculating cost effectiveness, the sixteen design modifications are those that achieve a rating of between 5 and 6 stars for the Kingston house. While a majority of these design changes result in a rating of between 5 and 6 stars for the Crimson and Hickman houses, the result in the case of some designs is a rating below 5 stars or above 6 stars.

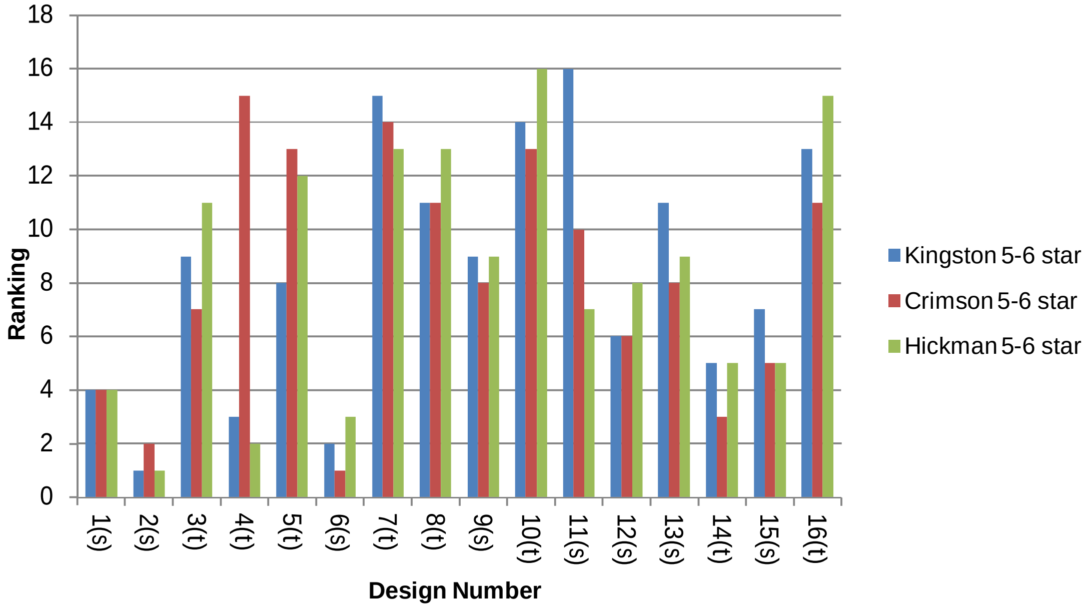


Figure 5.41 – Cost effectiveness rankings in minimizing embodied emissions

Overall, the most cost-effective design is the slab-on-ground Design 2. It ranks 1st for the Kingston and Hickman houses, and 2nd for the Crimson house. Design 11 is the lowest ranked design for the Kingston, Design 10 is the lowest ranked for the Hickman house, and Design 4 is lowest ranked design for the Crimson house. This demonstrates that there can be considerable variation in the ranking that a particular design modification provides for each house. However, the average range in ranking (the difference between the highest and lowest rank) that designs achieve for each house is 1.6.

Design 4 involved reducing window sizes in the living/dining and bedrooms and increasing the wall insulation to R2.5. On the other hand, Design 16 involved reducing the size of the living/dining room windows and adding R6 floor insulation and increasing the wall and ceiling insulation levels considerably, to R6.0 and R8.0, respectively.

Comparative increases in embodied energy (5-6 stars)

Figures 5.42 and 5.43 compare the increases in embodied energy for both floor types for each house. It can be seen that generally the increase in embodied energy (GJ/m2) that results from design change is similar for each house.

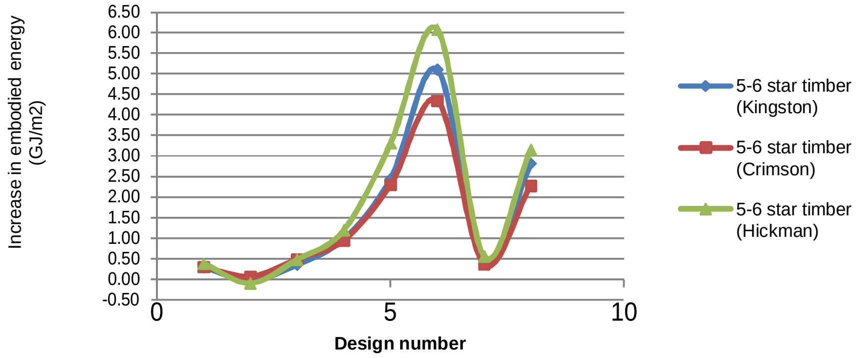


Figure 5.42 – Comparative increases in embodied energy (timber-floor)

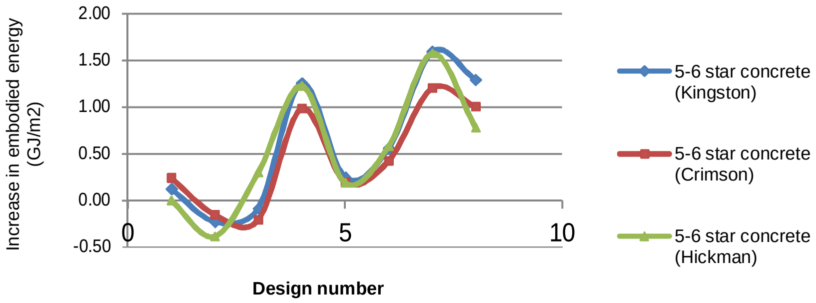


Figure 5.43 – Comparative increases in embodied energy (slab-on-ground)

Embodied energy versus cost (6-7 stars)

Kingston house

Figure 5.44 below shows that for both the timber floor and slab-on-ground designs, the correlation between cost and embodied energy is strong, though stronger for the timber-floor designs. Design 16, the most expensive design (along with Design 20), has the highest embodied energy. It had high levels of floor, wall and ceiling insulation added, and the living/dining room windows were reduced in size and double-glazed. The least expensive design, 5, has the lowest embodied energy. It had the living/dining and bedroom window reduced with the living/dining room windows double-glazed as well. R1.0 floor insulation was added and the wall and ceiling insulation increased modestly to R2.5 and R5.0 respectively.

However, there are designs that cost less than others with a similar or lower embodied energy. For example, Design 1, a timber floor design costs less than the slab-on-ground Design 14, but the increase in embodied energy of each one is similar. Design 1 had the living/dining and bedroom windows reduced in area and the living/dining room windows double-glazed. In addition, R3.0 floor insulation was added and wall and ceiling insulation increased modestly to R2.5 and R5.0 respectively. Design 14 has the same insulation changes as Design 1 and window areas were also reduced. However, while as for Design 1 the living/dining room windows were double-glazed, in addition the bedroom windows were also double-glazed. Design 14 also has tiles in lieu of carpet in the living/dining room and bedrooms, a modification which results in an increase in cost but a reduction in embodied energy. The reduction in embodied energy from the tiling offsets the greater increase in embodied energy from the larger area of double-glazed windows.

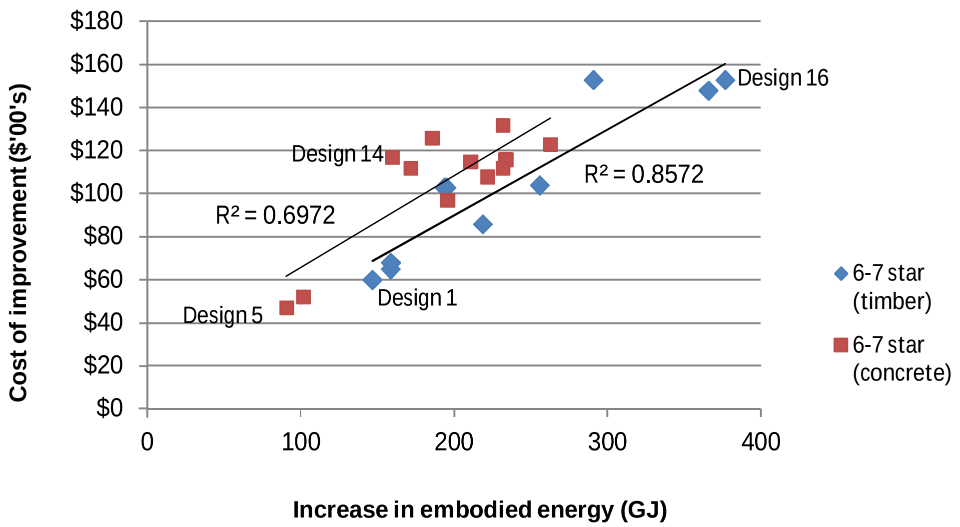


Figure 5.44 - Increase in embodied energy versus cost (Kingston)

Crimson house

Figure 5.45 shows that the correlation between cost and increase in embodied energy is strong for both the slab-on-ground and timber-floor designs. The most expensive design (Design 20) has the highest increase in embodied energy. It had high levels of floor, wall and ceiling insulation added, the windows in the living/dining room reduced in size, and the living/dining and bedroom windows double-glazed. The least expensive design (Design 2) has the lowest embodied energy. Its windows were reduced and double-glazed, and low to moderate levels of floor, wall and ceiling insulation added.

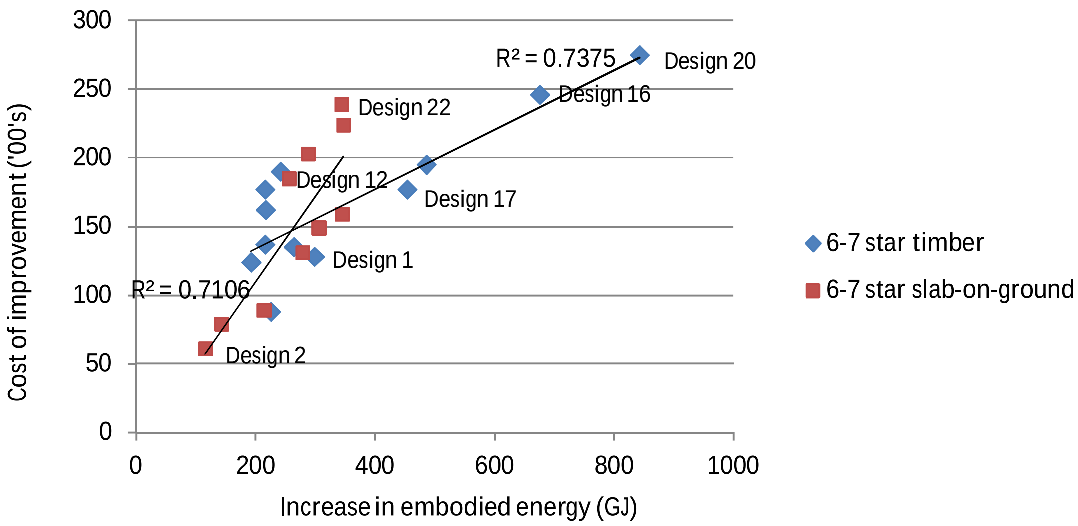


Figure 5.45- Increase in embodied energy versus cost (Crimson)

There are cases, where a timber floor and a slab-on-ground design are similar in cost, but the timber floor design has significantly higher increase in embodied energy. For example, the timber floor Design 8 has a higher embodied energy overall than the slab-on-ground Design 17 although the cost of their thermal performance improvements is the same. The main difference between the designs is that the timber floor has significantly higher levels of floor, wall and ceiling insulation than the slab-on-ground design, and that the slab-on-ground design has tiling in lieu of carpet in the living/dining and bedroom. The lower embodied energy of the slab-on-ground design is attributable to its lower insulation levels and tiles in lieu of carpet. That the cost of their improvements is the same is attributable to the tiles being more expensive than carpet, the additional cost of which is similar to the cost of the higher insulation levels of the timber-floor design, However, there are timber floor designs that cost less than slab-on-ground designs with a similar embodied energy. For example, the timber floor Design 1 is $5,700 less expensive than the slab-on-ground Design 12. The designs have the same levels of wall and ceiling insulation, though the timber-floor design has an extra R2.0 floor insulation and larger area of double-glazing, both of which increase cost and embodied energy. The additional 100mm slab and tiles in lieu of carpet for the slab-on-ground design results in a similar increase in embodied energy. However, the costs of the different design modifications are greater for the slab-on-ground design than for the timber-floor design.

Designs 16 and 22 are similar in cost. However, Design 16 has considerably higher embodied energy. The designs have the same glazing area and the same windows are double-glazed. They also have the same levels of wall and ceiling insulation. However, Design 16 has higher levels of polystyrene floor insulation than Design 22 whereas Design 22 has tiles in lieu of carpet in the bedroom and living/dining rooms. These design differences account for the disparity in embodied energy between the two designs. However, the use of tiles in Design 22, which are more expensive but have a lower embodied energy than carpet, results in the costs of the two designs being similar.

Hickman house

Figure 5.46 below shows that the correlation between cost and embodied energy is strong for both slab-on-ground and timber-floor designs. Design 14, the most expensive design, has the highest embodied energy, which is attributable to the high levels of floor, wall and ceiling insulation. In this case, the design with the lowest embodied energy, Design 1, is not the least expensive design. It is about $4,300 more expensive than the lowest cost design. This is mainly attributable to Design 1 having timber in lieu of aluminium windows, which have a lower embodied energy than aluminium windows but cost more per/m2.

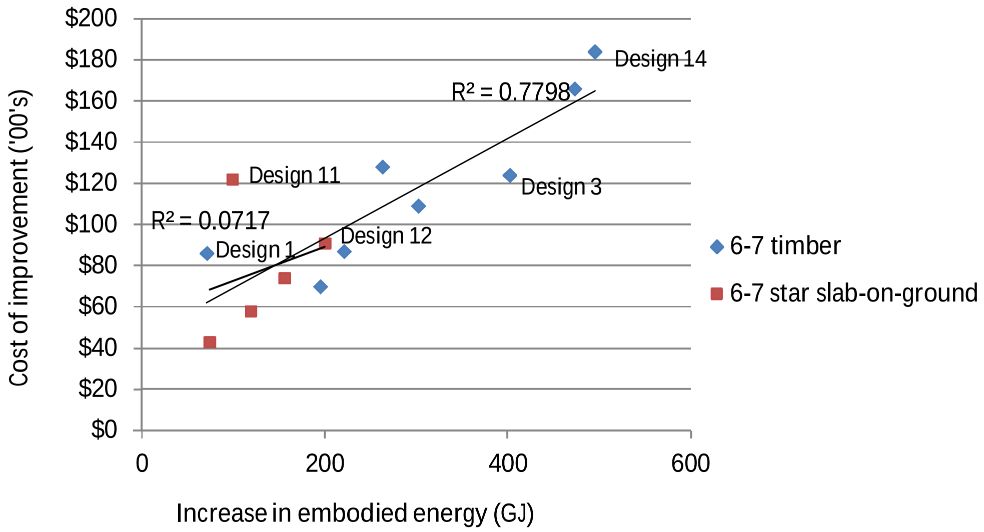


Figure 5.46 - Increase in embodied energy versus cost (Hickman)

There is one case where a timber floor design with a similar cost to a slab-on-ground design has a lower increase in embodied energy (4% and 11% increase in embodied energy for the timber-floor and slab-on-ground designs, respectively). Design 1 has a lower embodied energy than Design 12 because of its lower levels of wall and ceiling insulation and also because it has timber framed windows in lieu of aluminium. However, the extra cost of the timber-framed windows approximates the cost of the extra wall and ceiling insulation used in Design 12.

Conversely, the slab-on-ground Design 11, and the timber floor Design 3, are similar in cost. However, the timber floor design has a significantly higher increase in embodied energy. Its embodied energy increased by 21% whereas the embodied energy of Design 11 increased by 5%. Both designs have the same glazing area and glazing type, and the same levels of wall and ceiling insulation. Design 3 has high levels of floor insulation and Design 11 has none, whereas Design 3 has aluminium-framed windows and Design 11 has timber-framed windows. These design differences account for the difference in embodied energy while the extra cost of the timber windows approximates the cost of the floor insulation.

Cost effectiveness of thermal performance improvements in reducing embodied emissions (6-7 stars)

Figure 5.47 below shows a comparison of the ranking of the cost effectiveness of thermal performance improvements in minimising the resulting increase in embodied emissions for the three houses in the 6-7 star band range. Overall, Designs 2 and 14 are the most cost effective designs. The figure shows that there can be a considerable difference in the ranking a particular design provides for each house. For example, Design 15 is ranked 2nd for the Kingston and Crimson houses but 8th for the Hickman house. It is evident therefore that the cost effectiveness of measures (in this case in avoiding an increase in embodied emissions) will vary depending on the materials and methods used. In addition, the cost effectiveness of a thermal performance measure can vary significantly depending on the house to which it is applied.

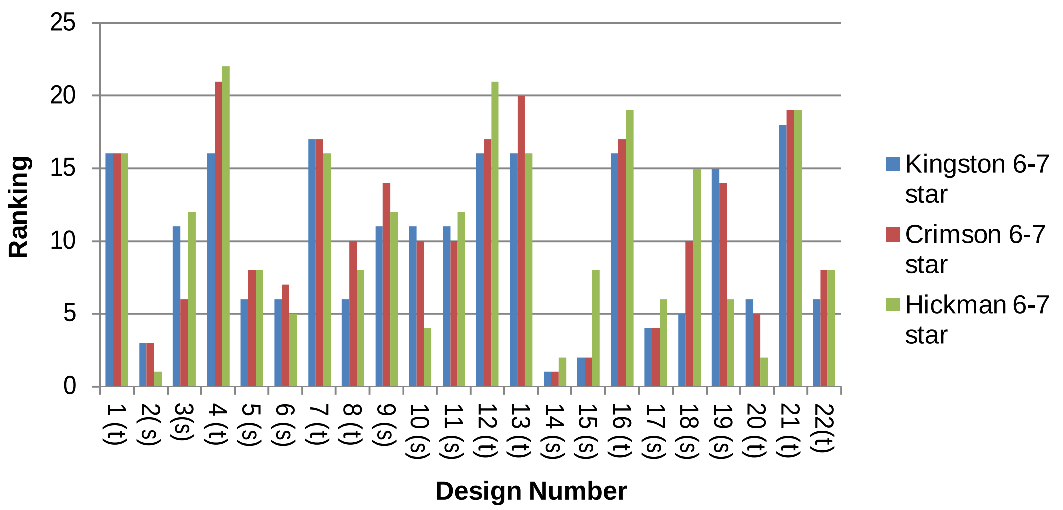


Figure 5.47 – Cost effectiveness rankings in minimizing embodied emissions (6-7 stars)

Comparative increases in embodied energy (6-7 stars)

Figures 5.48 and 5.49 compare the increases in embodied energy for both floor types for each house. It can be seen that generally the increase in embodied energy (GJ/m2) that results from design changes is lowest for the Crimson house.

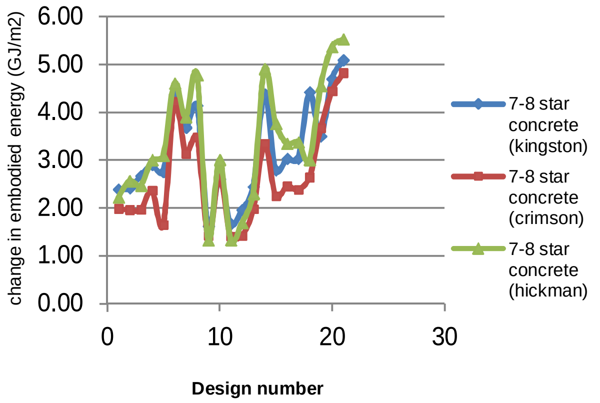


Figure 5.48 – Comparative increases in embodied energy (timber-floor)

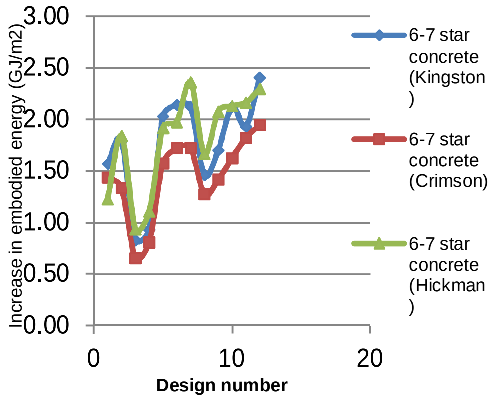


Figure 5.49 – Comparative increases in embodied energy (slab-on-ground)

Cost versus embodied energy (7-8 stars)

Kingston house

Figure 5.50 below shows that the correlation between embodied energy and cost is weaker for designs in this star band range than it is for the lower star band ranges. An indication of the extent to which the correlation between embodied energy and cost has weakened is that Design 3 has a higher increase in embodied energy but is less expensive than almost 50 % of the other designs in this star band range. Design 3 had the living/dining room and bedroom windows reduced in size and double-glazed, and moderate levels of floor and high levels of wall and ceiling insulation added (R6.0 and R8.0 respectively). The other designs had similar insulation levels as Design 3, although the design modification that led to them having a lower increase in embodied energy while being more expensive was a greater area of tiling and/or triple glazing. While timber-framed triple-glazed are considerably more expensive than double-glazed aluminum windows, their embodied energy is lower (the lower embodied energy of the timber versus aluminium frame offsets the increase in embodied energy that results from an extra pane of glass). And, as previously discussed, tiles are less expensive than carpet but have a lower embodied energy.

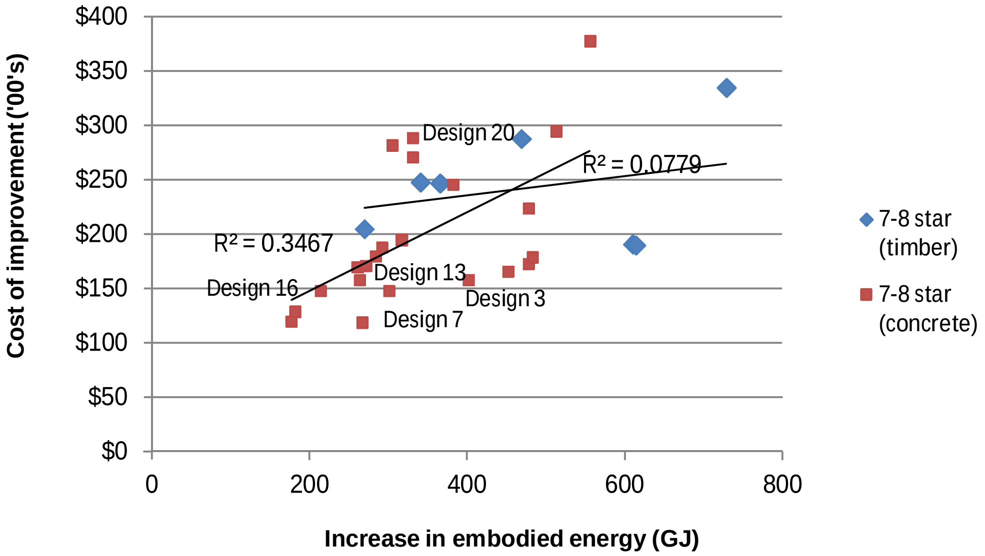


Figure 5.50 – Increase in embodied energy versus cost (Kingston)

There are examples of designs with similar embodied energy but which vary significantly in cost and examples where the reverse is true. For example, Design 13 is approximately $11,000 less expensive than Design 20. Both are slab-on-ground designs with the same windows area, tiles in lieu of carpet, and the same level of floor insulation. The difference is that Design 20 has triple rather than double-glazing, a thicker slab, and lower levels of wall and ceiling insulation. The net increase in embodied energy of Design 20 that results from triple glazing and a thicker slab approximates the net increase in embodied energy of Design 13 that results from the extra wall and ceiling insulation. However, Design 20 is considerably more expensive.

Two slab-on-ground designs, 7 and 16, cost the same but Design 16 has a lower increase in embodied energy (20% increase versus 14% increase). Both designs have the same glazing area and the same windows are double-glazed. While Design 16 has a thicker slab, it has less wall and ceiling insulation than Design 7, and timber in lieu of aluminium windows, resulting in a lower embodied energy but a more expensive design.

Crimson house

Figure 5.51 shows that as for the Kingston house, the correlation between cost and embodied energy is weaker in this star band range than it is for lower star bands. The designs with the highest and lowest embodied energy are not the most and least expensive designs respectively.

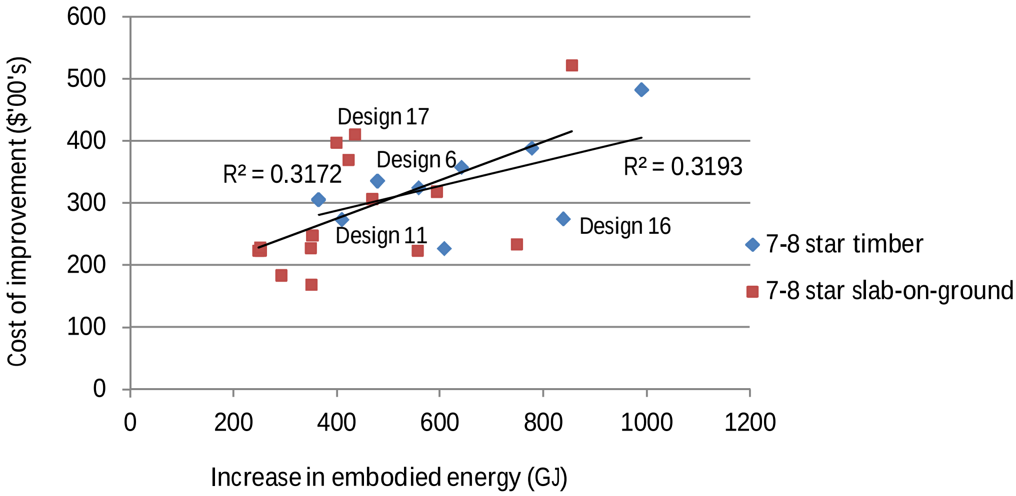


Figure 5.51 – Increase in embodied energy versus cost (Crimson)

There are designs with the same or similar embodied energy, which vary significantly in cost and designs where the reverse is true. For example, the Designs 11 and 17 have a very similar increase in embodied energy. However, Design 17 is approximately $13,700 more expensive. The difference in cost is because Design 17 has triple-glazed timber windows instead of double-glazed aluminium windows and higher insulation levels, which result in a significantly more expensive design. However, the increase in embodied energy from the higher insulation levels is offset by the decrease in embodied energy resulting from the use of timber-framed windows.

The Designs 11 and 16 cost about the same though the net increase in embodied of Design 16 is significantly greater (34% increase versus 16% increase). Both designs have the same window area and the same windows are double-glazed. However, the Design 16 has significantly higher levels of floor, wall and ceiling insulation, whereas the Design 11 had its slab thickness doubled and tiles in lieu of carpet. The cost of higher insulation levels approximates that of the lower embodied energy modification of a thicker slab and tiles used in the slab-on-ground design.

The timber floor Design 6, and the slab-on-ground Design 22, cost about the same though the timber floor design has a lower increase in embodied energy (19% increase versus 26% increase). The two designs have the same window area. However, in the living/dining and bedrooms the timber floor design has triple-glazed timber framed windows whereas the slab-on-ground design has double-glazed timber-framed windows. The slab-on-ground design has significantly higher levels of wall and ceiling insulation than the timber-floor design while having a lower level of floor insulation. The cost of the triple glazing approximates the net cost increase of the overall higher insulation levels and tiles used in the slab-on-ground design but results in a lower increase in embodied energy.

Hickman house

Figure 5.52 shows that the correlation between an increase in embodied energy and cost is moderate (and very similar) for the slab-on-ground and timber floor designs. For both floor types, it is stronger than it is for the Kingston and Crimson houses within the same star band range. The reasons for this are discussed in Chapter 6. The least expensive and most expensive designs have the lowest and highest embodied energy respectively.

There are slab-on-ground designs with a similar cost but whose increase in embodied energy varies significantly for example Designs 17 and 33 (a 22% increase versus 9% increase in embodied energy). The two designs have the same window area and the same windows are double-glazed. However, Design 33 has lower levels of wall and ceiling insulation (lower by R3.5 and R5.0), tiling in lieu of carpet, and timber-framed windows, resulting in a lower increase in embodied energy (but similar in cost) as the higher insulation levels of Design 17.

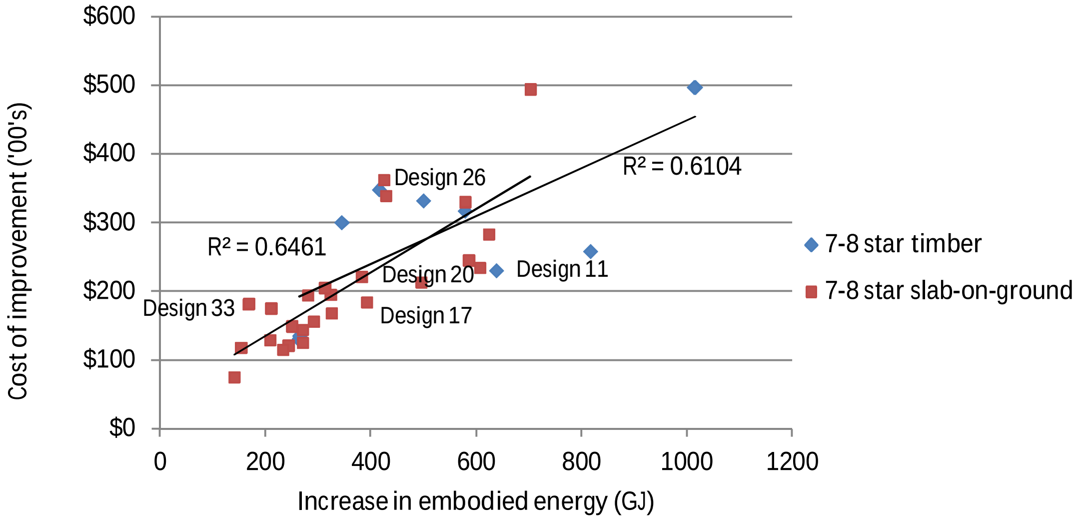


Figure 5.52 – Increase in embodied energy versus cost (Hickman)

The timber floor Design 11 costs less than slab-on ground designs that have a similar embodied energy. Its level of thermal performance has been achieved in part from removing downlights and changing the external wall colour from light to dark, neither of which increase embodied energy.

The slab-on-ground Designs 20 and 26, have a similar embodied energy. However Design 26 costs about $13,500 more. While both designs have the same window area, Design 20 has aluminium-framed double-glazed windows in the living/dining and bedrooms whereas in the same rooms Design 26 has timber-framed triple-glazed windows. Design 22 has significantly higher levels of wall and ceiling insulation than Design 26 (R2.5 and R5.0 versus R8.0 and R10.0). Design 22 has tiles in lieu of carpet in the living/dining room whereas Design 26 has tiles in lieu of carpet in the bedrooms as well and its slab thickness has been doubled. The net increase in embodied energy for Design 26 that results from doubling the slab thickness, switching to timber windows and using tiles in lieu of carpet in living/dining and bedrooms approximates the net increase in embodied energy for Design

20 that results from its comparatively higher levels of wall and ceiling insulation. The higher cost of Design 26 is attributable to the use of the more expensive timber-framed triple-glazing.

Cost effectiveness of thermal performance improvements in reducing embodied emissions (7-8 stars)

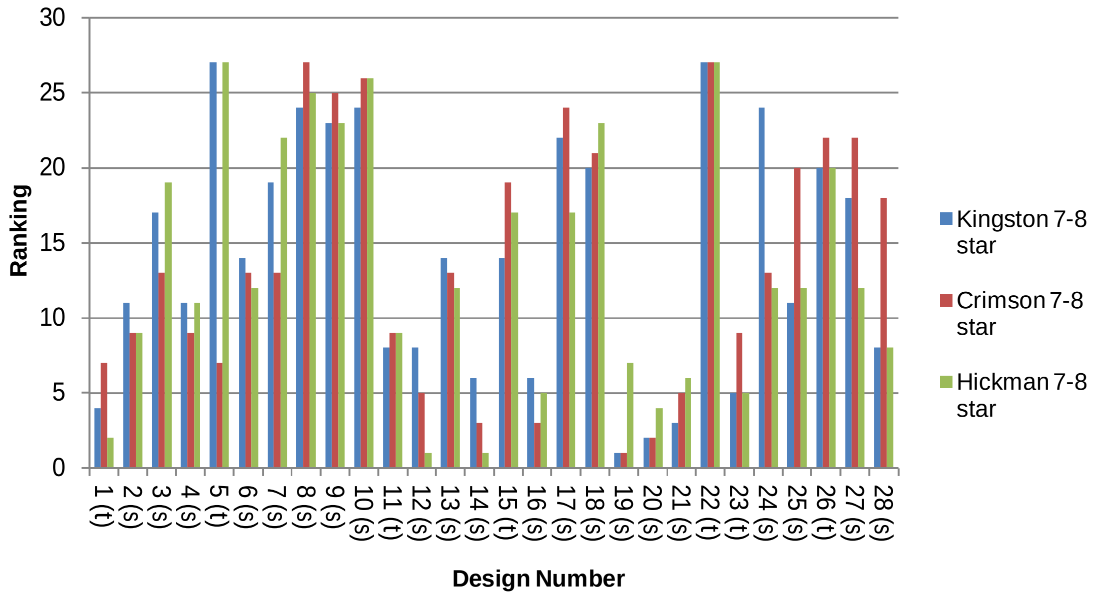


Figure 5.53 – Cost effectiveness rankings in minimizing embodied emissions (7-8 stars)

Figure 5.53 shows a comparison of the ranking of the cost effectiveness of thermal performance improvements in minimising the resulting increase in embodied emissions for the three houses in the 7-8 star band range. It shows that there can be a considerable difference in the ranking a particular design provides between houses. For example, Design 28 is ranked 8th for the Kingston and Hickman houses, but is ranked 18th for the Crimson house. Design 5 is ranked 7th for the Crimson house and 26th for the Kingston and Hickman houses.

Designs 14, 16, 20 and 21 are generally the most cost effective designs, providing the lowest ranking of 6 for any one house. The insulation levels of each design are generally very modest; R3.0 floor, R2.5 wall and R5.0 ceiling. The average range in ranking of designs for the houses is 4.5

Comparative increases in embodied energy (7-8 stars)

Figures 5.54 and 5.55 compare the increases in embodied energy for both floor types for each house. It can be seen that generally the increase in embodied energy (GJ/m2) that results from design changes is highest for the Hickman house, for both floor types.

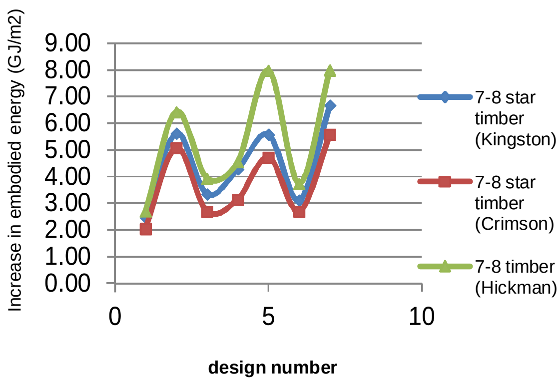


Figure 5.54 – Comparative increases in embodied energy (timber-floor)

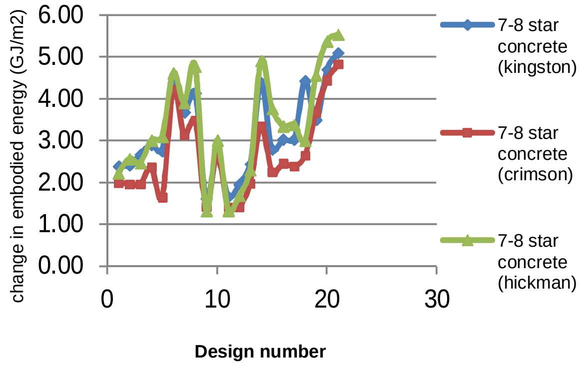


Figure 5.55 – Comparative increases in embodied energy (slab-on-ground)

5.5 COMPARISON OF EMBODIED CO_2-e AND SPACE-CONDITIONING CO_2-e COST EFFECTIVENESS RANKINGS

The following section compares the rankings in the designs' cost effectiveness for avoiding (or minimizing) embodied emissions and in saving space-conditioning emissions. A considerable difference between the two would suggest that what is cost effective in saving space-conditioning emissions may not necessarily be cost effective in saving net emissions (net emissions being space-conditioning emissions saved minus the increase in embodied emissions), or vice versa.

5-6 star band range

Kingston

Figure 5.56 below shows the cost effectiveness ranking of thermal performance improvements in reducing space-conditioning emissions with their cost effectiveness ranking in minimising the net increase in the embodied emissions, for the 5-6 star Kingston house.

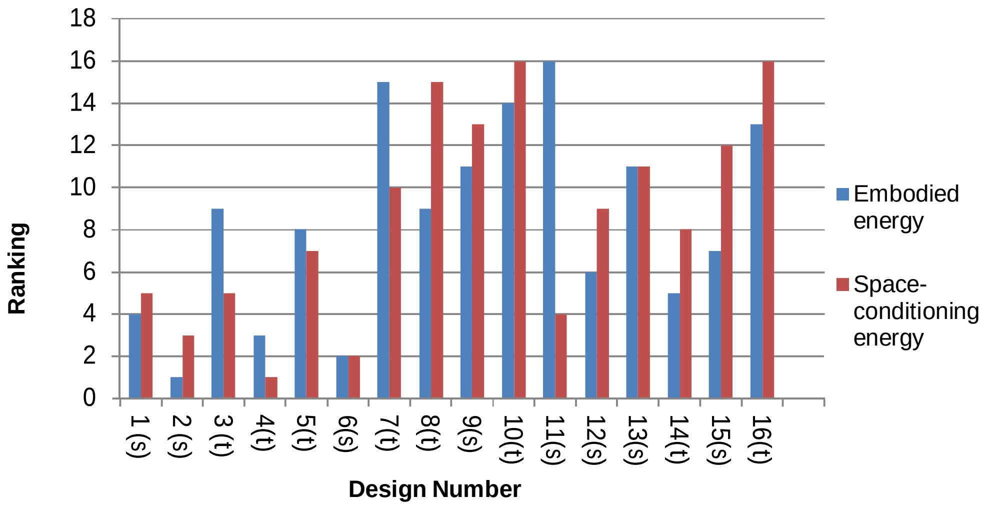


Figure 5.56 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Kingston)

Design 4 is the most cost effective design in reducing space-conditioning emissions and ranked 3rd for minimizing net increase in embodied emissions. Design 2 is the most cost effective design in minimizing the net increase in embodied emissions, and ranked 3rd for reducing space-conditioning emissions. Along with Design 10, Design 16 is the least cost effective design (ranked 16th) in saving space-conditioning emissions and ranked 13th in minimizing embodied emissions.

Crimson

Figure 5.57 below shows that for the Crimson house Design 2 is the most cost effective design in reducing space-conditioning emissions and ranked 2nd for minimizing net increase in embodied emissions. Design 6 is the most cost effective design in minimizing the net increase in embodied emissions while it is ranked 3rd for reducing space-conditioning emissions. Design 4 is the least cost effective design (16th) in minimizing the net increase in embodied emissions, but is ranked 2nd for cost effectiveness in reducing space-conditioning emissions. Design 10 is the least cost effective (ranked 16th) in reducing space-conditioning emissions. For several designs, the difference in ranking between their cost effectiveness in saving space-conditioning emissions and cost effectiveness in minimizing the net increase in embodied emissions, is significant. For Designs 4, 14 and 15 the difference in the cost effectiveness ranking for the two measures is at least 8. It is worth noting that the most cost effective designs in saving space-conditioning emissions are the lowest cost designs within the star band range.

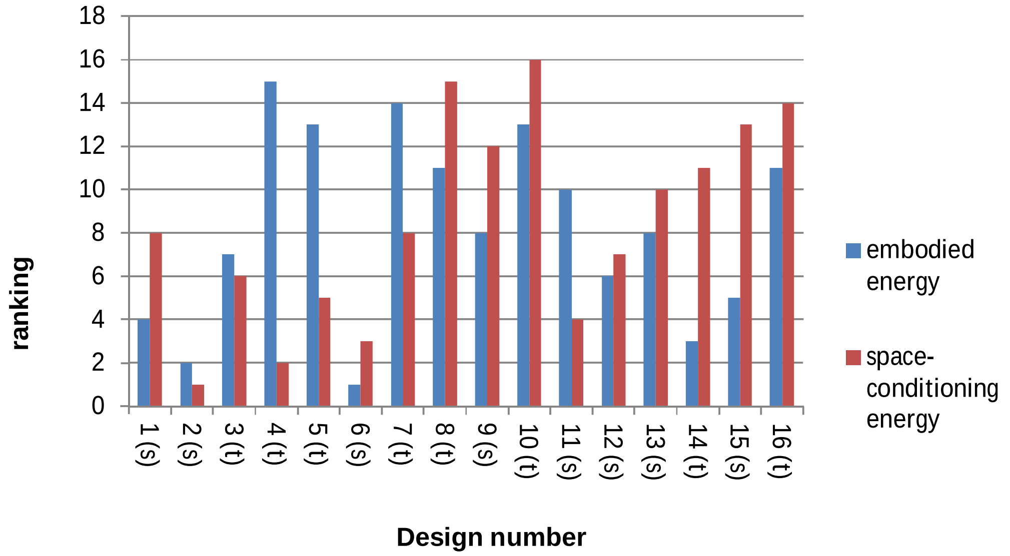


Figure 5.57 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Crimson)

Hickman

Figure 5.58 below shows that for the Hickman house, Design 2 is the most cost effective design in minimizing the net increase in embodied emissions, and is ranked 3rd for cost effectiveness in reducing space-conditioning emissions. Design 4 and 6 rank equal 1st in their cost effectiveness in reducing space-conditioning emissions, while they rank 2nd and 3rd respectively for cost effectiveness in minimizing the net increase in embodied emissions.

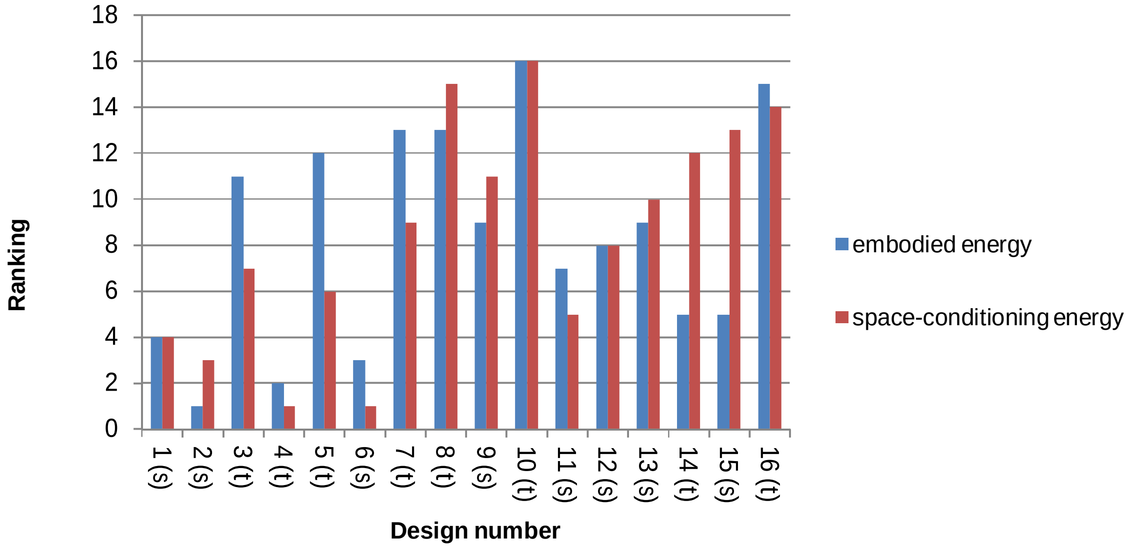


Figure 5.58 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Hickman)

Design 10 is the least cost effective designs in both reducing space-conditioning emissions and minimizing net embodied emissions. As for the Crimson house, there are several designs where the differences in ranking between their cost effectiveness in saving space-conditioning emissions and cost effectiveness in minimizing the net increase in embodied emissions, is significant. For Designs 5, 14 and 15 the difference in the cost effectiveness ranking for the two measures is at least 6.

Summary 5-6 star band

Design 4 is the most cost effective design in reducing space-conditioning emissions for the Kingston and Hickman houses and Design 2 is the most cost effective design in minimizing net embodied emissions for the Kingston and Hickman houses. Design 10 is the least cost effective designs in reducing space-conditioning emissions for both the Kingston and Crimson houses.

Table 5.26 shows that the average difference in ranking for designs is 3 for the Kingston and Hickman houses and 5 for the Crimson house.

Table 5.26 – Average difference in ranking between cost effectiveness rankings (5-6 star band)

Kingston	3
Crimson	5
Hickman	3

6-7 Stars

Kingston

Figure 5.59 shows the cost effectiveness ranking of thermal performance improvements in reducing space-conditioning emissions with their cost effectiveness ranking in minimising the net increase in the embodied emissions, for the Kingston house in the 6-7 star band range.

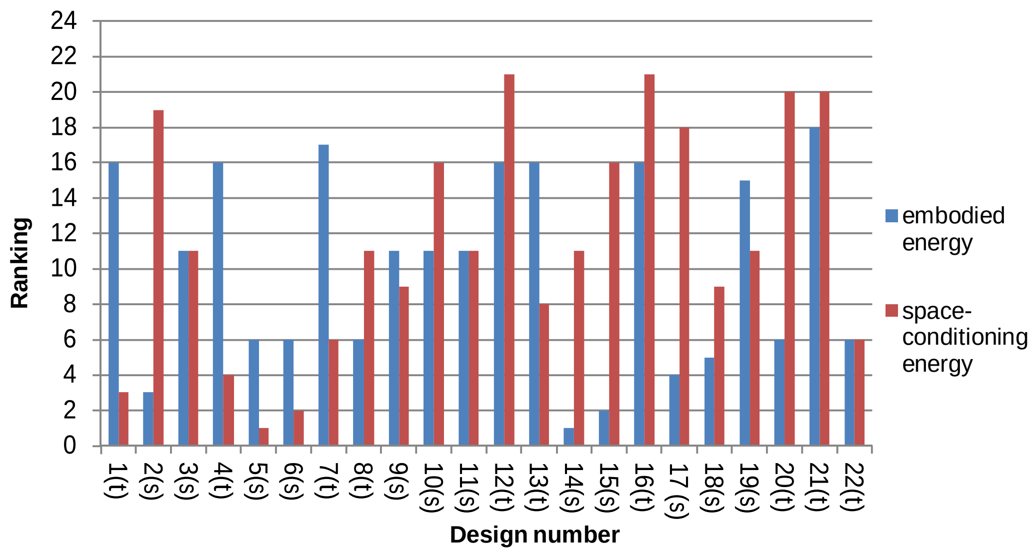


Figure 5.59 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Kingston)

For the Kingston house, Designs 14 and 5 are the most cost effective in minimizing the increase in net embodied emissions and in reducing space-conditioning emissions, respectively. Designs 21, and 12 together with 16, are least cost effective in minimizing the net increase in reducing space-conditioning emission and minimizing embodied emissions, respectively.

Crimson

Figure 5.60 shows that for the Crimson house, Designs 4 and 14 are the most cost effective for reducing space-conditioning emissions and minimising the net increase in embodied emissions, respectively. Interestingly, Design 4 is the least cost effective in minimising the net increase in embodied emissions. Design 22 is the least cost effective design in reducing space-conditioning emissions.

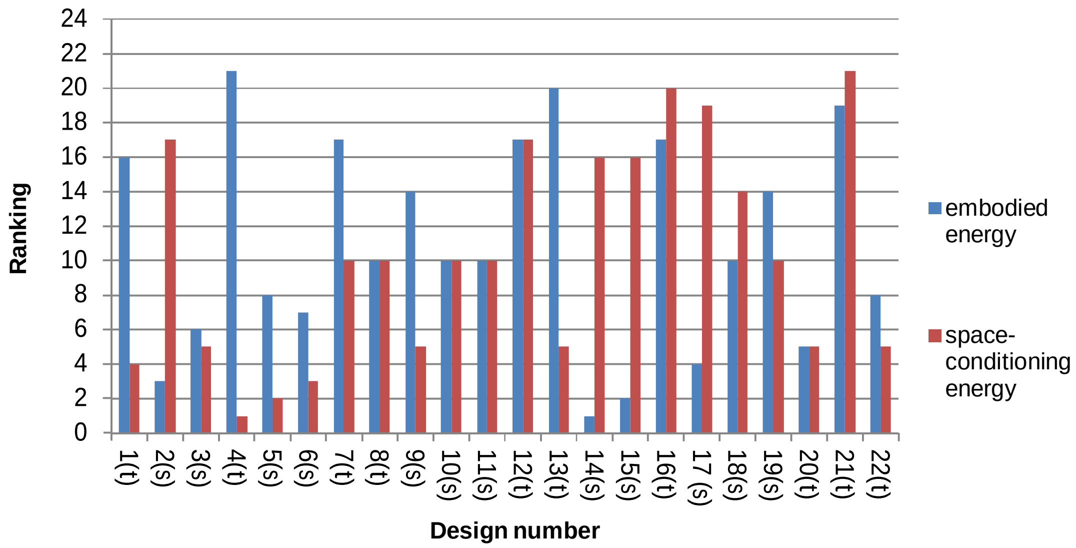


Figure 5.60 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Crimson)

Hickman

Figure 5.61 shows that for the Hickman house, Designs 2 and 4 are the most cost effective for minimisng the net increase in embodied emissions and reducing space-conditioning emissions, respectively. As for the Crimson house, Design 4 while being the most cost effective in reducing space-conditioning emissions, is the least cost effective in minmising the net increase in embodied emissions. Design 21 is the least cost effective in reducing space-conditioning emissions.

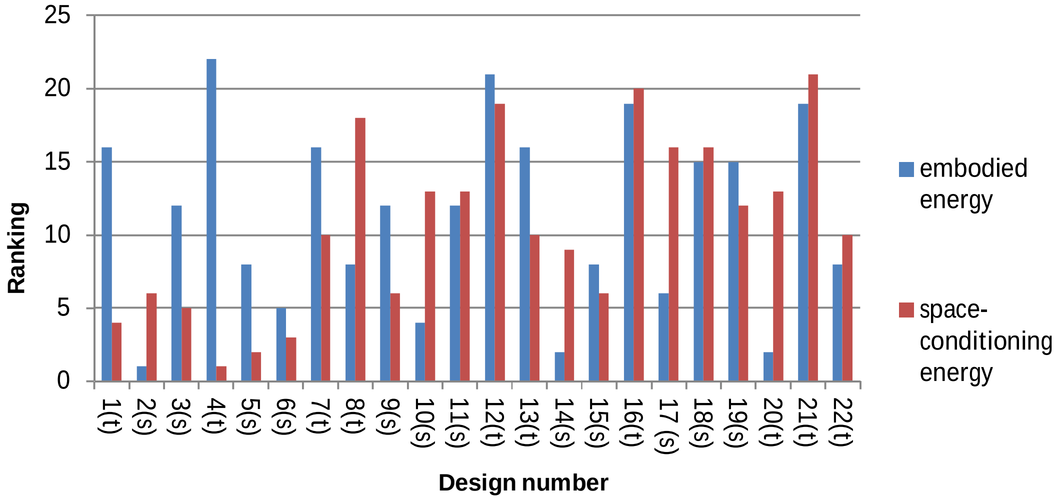


Figure 5.61 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Hickman)

Summary of the 6-7 star band

The average difference in ranking between the two measures is 7 for the Kingston and Crimson houses, and 6 for the Hickman house (see table 5.27 below). These differences are greater than they are for designs in the 5-6 star band range. In this star band range Design 4 and 21 are the only designs that are either the most or least cost effective design for more than one house.

Table 5.27 – Average difference in ranking between cost effectiveness rankings (6-7 star band)

Kingston	7
Crimson	7
Hickman	6

7-8 STARS

Kingston

Figure 5.62 shows the cost effectiveness ranking of thermal performance improvements in reducing space-conditioning emissions with their cost effectiveness ranking in minimising the net increase in the embodied emissions, for the Kingston house in the 7-8 star band range.

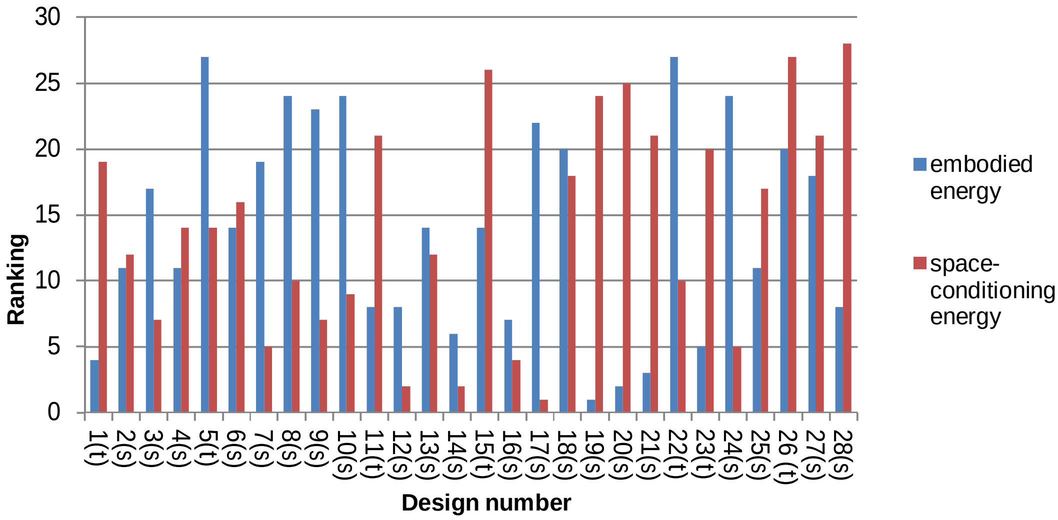


Figure 5.62 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Kingston)

For the Kingston house, Designs 19 and 17 are the most cost effective in minimising the net increase in embodied emissions and reducing space-conditioning emissions, respectively, whereas Designs 5 (togther with 22) and 28 are the least cost effective in minimising the net increase in embodied emissions and reducing space-conditioning emissions, respectively. By contrast with the lower star band ranges, the range in ranking between several designs is considerable, the reasons for which are discussed in Chapter 6.

Crimson

Figure 5.63 shows that as for the Kingston house, Designs 17 and 19 are the most cost effective in reducing space-conditioning emissions and minimising the net increase in embodied emissions, respectively. Designs 8 and 22 are the least cost effective in minimising the net increase in embodied emissions (ranked equal 27th) and Design 28 is the least cost effective in reducing space-conditioning emissions.

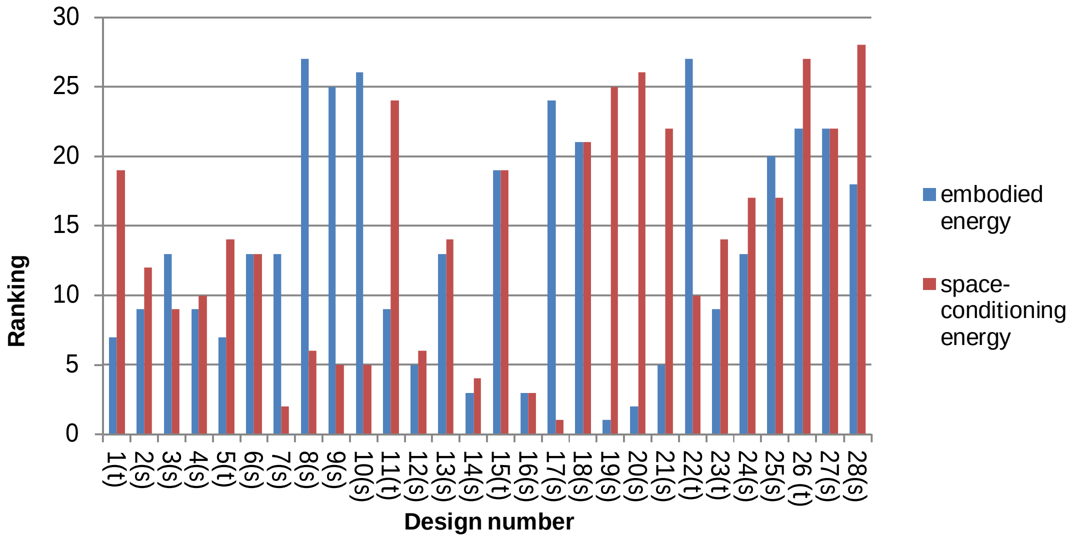


Figure 5.63 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Crimson)

Hickman

As for the Kingston and Crimson houses, Design 17 is the most cost effective in reducing space-conditioning emissions and Design 19 is the most cost effective in minimising the net increase in embodied emissions. Designs 22 and 8 are the least cost effective in minimising the net increase in embodied emissions and Design 28 is the least cost effective in reducing space-conditioning emissions. There is a considerable difference in ranking for several designs, the reasons for which are addressed in Chapter 6.

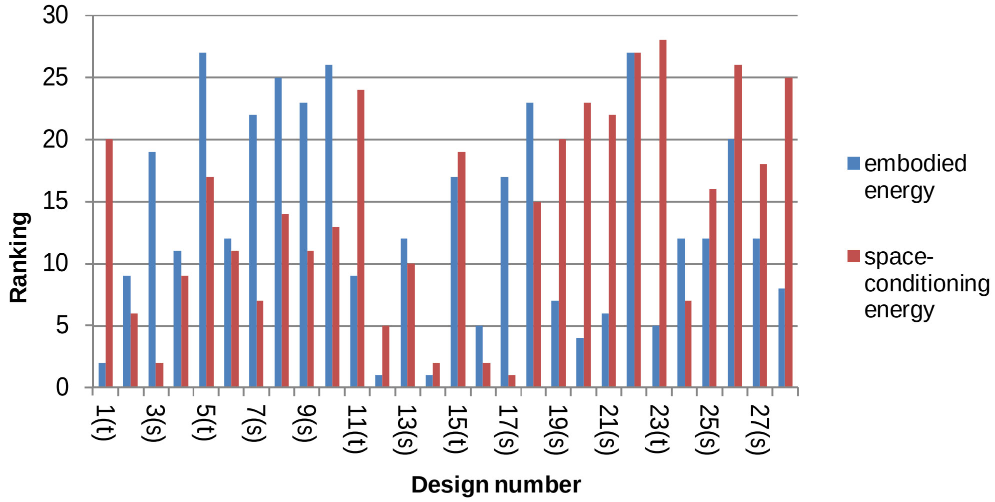


Figure 5.64 – Cost effectiveness comparison: savings in embodied and space-conditioning CO_2-e (Hickman)

Summary of the 7-8 star band

Designs 19 and 17 are the most cost effective design in minimizing the net increase in embodied emissions and reducing space-conditioning emissions, respectively, for all houses. Design 22 is the least cost effective design in minimizing the net increase in embodied emissions for all houses, and Design 28 is the least cost effective in reducing space-conditioning emissions for all houses.

Table 5.28 shows the average difference in ranking for the two measures in the 7-8 star band range. While the range in ranking between houses is greatest in this star band range, the designs which are the most and least cost effective for both measures are common to each house,

Table 5.28 – Average difference in ranking between cost effectiveness rankings (7-8 star band)

Kingston	11
Crimson	9
Hickman	10

The results in this section showed that the difference in ranking between saving space-conditioning emissions and minimizing embodied emissions becomes wider as thermal performance increases. The reasons for this are discussed in the Chapter 6.

5.6 COMPARISON OF COST EFFECTIVENESS RANKINGS OF EMBODIED ENERGY, SPACE-CONDITIONING AND NET EMISSIONS SAVINGS

The following section compares the rankings of designs' cost effectiveness for avoiding (or minimizing) embodied emissions and in saving space-conditioning and net emissions. The purpose of comparing the three measures is to determine whether a design's cost effectiveness ranking in either avoiding embodied emissions or saving space-conditioning emissions is a reliable indicator of its cost effectiveness ranking is saving net emissions.

5-6 star band

Kingston

Figure 5.65 below compares the ranking in cost effectiveness of savings in embodied emissions, space-conditioning and net emissions (where net emissions are the result of adding savings in space-conditioning emissions to the resulting increase in embodied emissions).

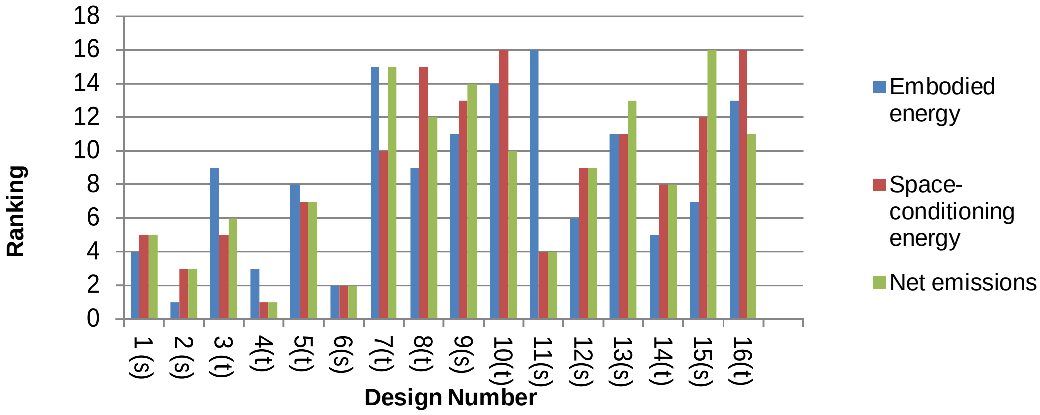


Figure 5.65 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Kingston)

Figure 5.65 above shows that Design 4 is the most cost effective in saving net emissions as well as space-conditioning emissions for the Kingston house. Design 2 is the most cost effective in saving embodied emissions. Designs 10, 16, 11 and 15 are the least cost-effective (ranked 16th) in saving space-conditioning, embodied and net emissions, respectively. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 0.9, whereas the average difference between the cost effectiveness ranking in saving net emissions and embodied emmission is 2.4.

Crimson

Figure 5.66 below shows that Design 6 is the most cost effective in saving net emissions as well as embodied emissions for the Crimson house. As for the Kingston house, Design 10 is the least cost-effective design (ranked 16th) in saving space-conditioning emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 1.4, whereas the average difference between the cost effectiveness ranking in saving net emissions and embodied emmission is 3.9.

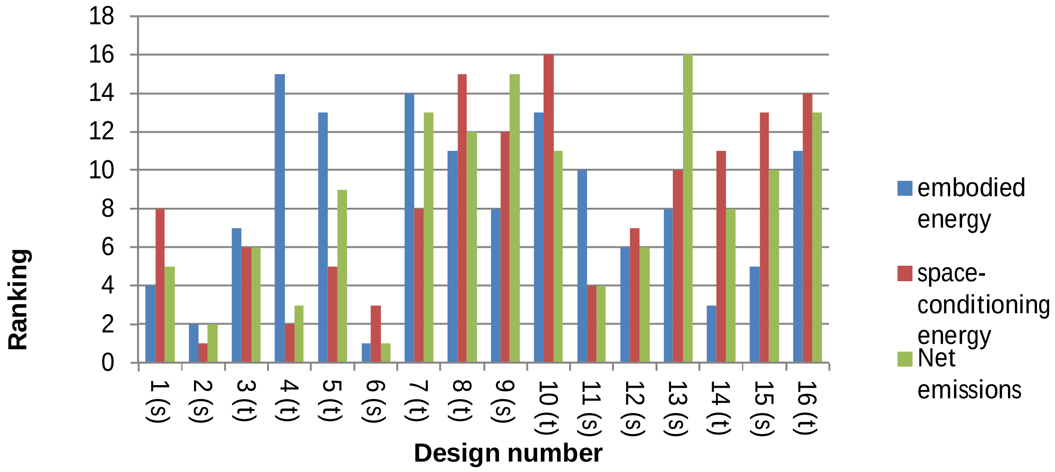


Figure 5.66 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Crimson)

Hickman

Figure 5.67 below shows that Designs 4 and 6 are the most cost effective in saving net emissions as well as space-conditioning emissions for the Hickman house. As for the Kingston and Crimson house, Design 10 is the least cost-effective design (ranked 16th) in saving space-conditioning emissions. In this case Design 10 is also the least cost effective in saving embodied emissions, and Design 16 is the least cost effective in saving net emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 0.8, whereas the average difference between the cost effectiveness ranking in saving in net emissions and embodied emissions is 2.6.

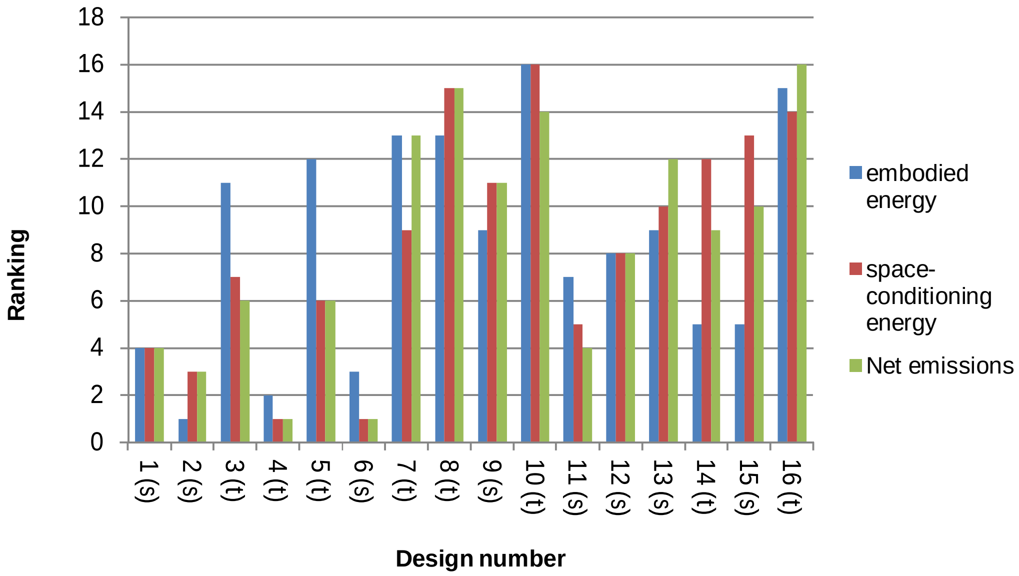


Figure 5.67 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Hickman)

Summary of the 5-6 star houses

There is little difference in a design's cost effectiveness ranking for savings in net and savings in space-conditioning emissions. For each house the designs that are the most and least cost effective in saving space-conditioning emissions are also the most and least cost effective in savings net emissions, respectively. Generally, a design's cost effectiveness ranking in saving in space-conditioning emissions is a reasonable predictor of its cost effectiveness ranking in saving net emissions, with the average difference in ranking between net and space-conditioning emissions is lower than it is between net and embodied emissions, for each house. The reasons for this are discussed further in Chapter 6.

6-7 STARS

Kingston

Figure 5.68 below shows that for the Kingston house Design 5 is the most cost effective in saving net emissions as well as space-conditioning emissions. Design 15 is the least cost-effective design (ranked 22nd) in saving net emissions, whereas Designs 12 and 16 are the least cost-effective in saving space-conditioning emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 3.6, whereas the average difference between the cost effectiveness ranking in saving in saving net emissions and embodied emissions is 4.3.

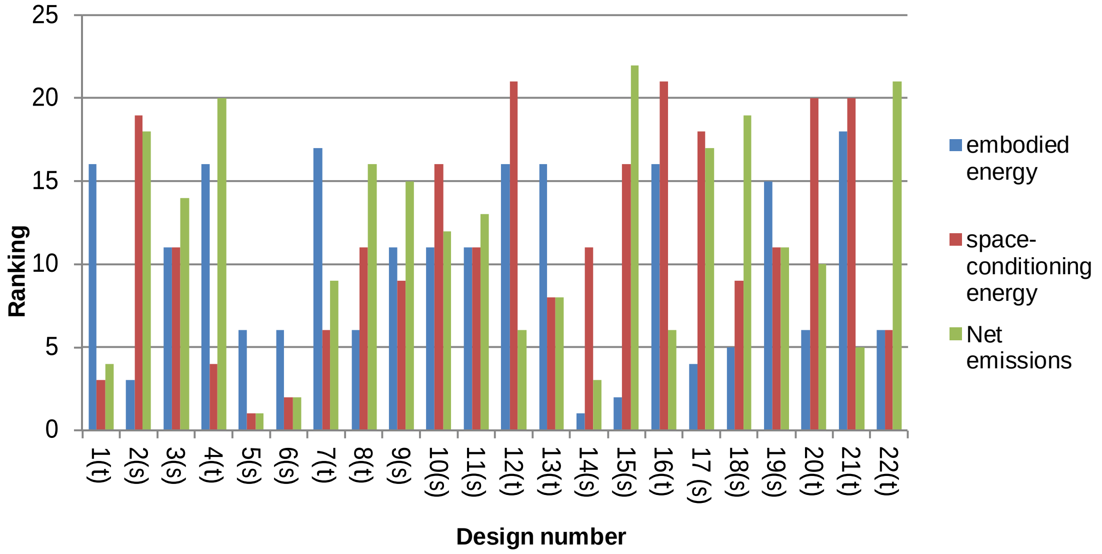


Figure 5.68 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Kingston)

Crimson

Figure 5.69 below shows that as for the Kingston house, Design 5 is the most cost effective in saving net emissions for the Crimson house, but is ranked 2nd in its cost effectiveness in saving space-conditioning emissions. Design 21, 15 and 4 are the least cost-effective designs in saving space-conditioning, net and embodied emissions, respectively. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 5.9, whereas the average difference between the cost effectiveness ranking in saving net emsiions and embodied emissions is 4.5.

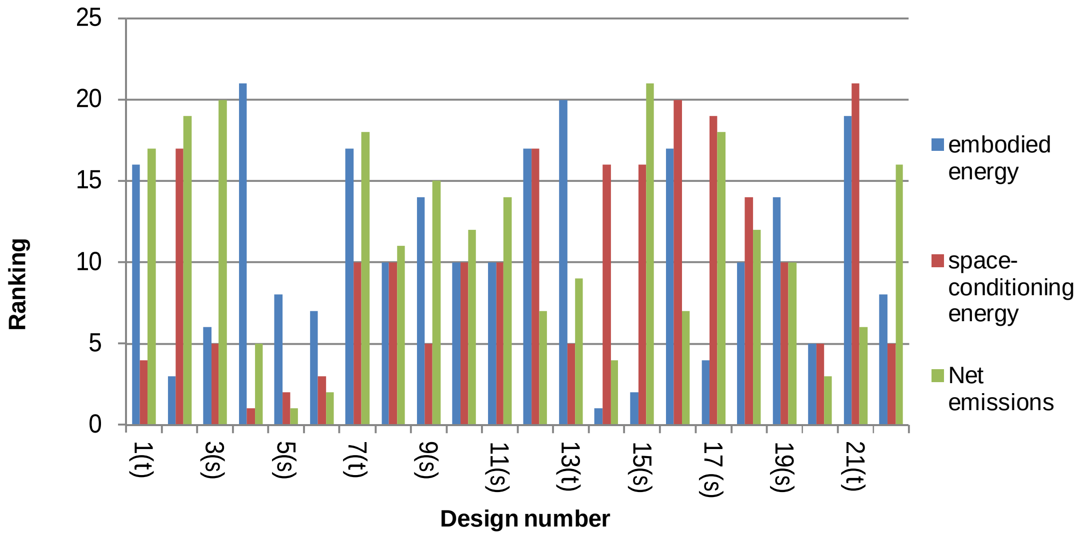


Figure 5.69 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Crimson)

Hickman

Figure 5.70 below shows that as for the Kingston and Crimson houses, Design 5 is the most cost effective in saving net emissions for the Hickman house, and that like the Crimson house, it is ranked 2nd in its cost effectiveness in saving space-conditioning emissions. Design 12 is the least cost-effective design (ranked 22nd) in saving embodied emissions whereas Design 21 is the least cost-effective in saving space-conditioning emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning, as well as between net emissions and embodied emmission, is 3.6.

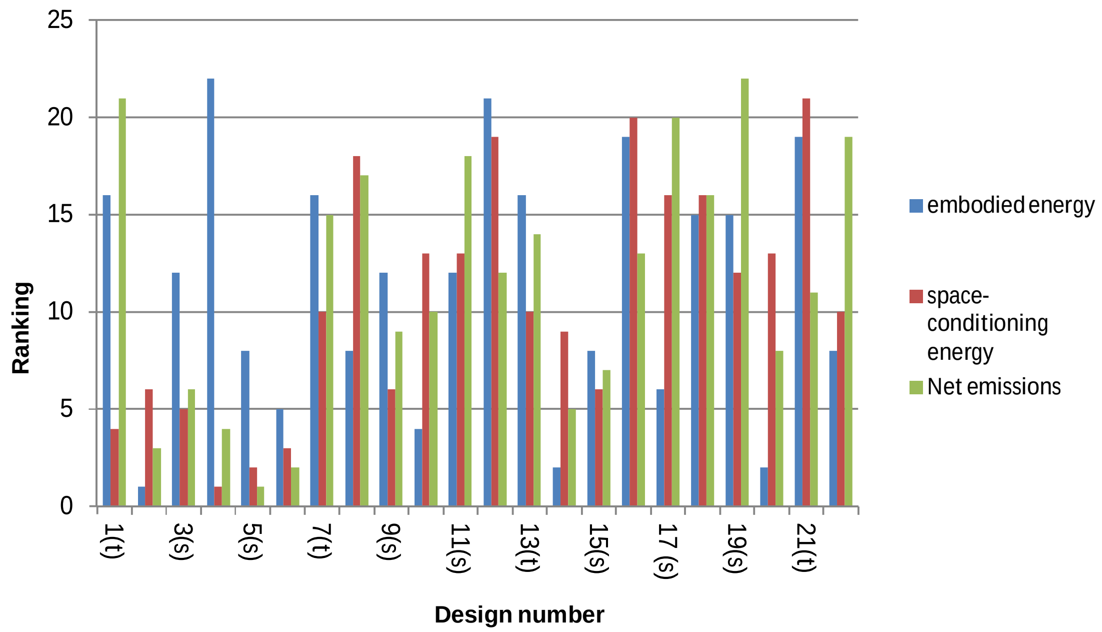


Figure 5.70 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Hickman)

Summary of the 6-7 star houses

The average difference in the cost effectiveness ranking between savings in net emissions and space-conditioning emissions, as well as between savings in net emissions and embodied emissions is greater than it is for the 5-6 star band range. Generally, for the Kingston and Crimson houses, cost effectiveness in saving space-conditioning emissions is a marginally better predictor of cost effectiveness in saving net emissions than minimizing the increase in embodied emissions. However, for the Hickman house, one is no better than the other. The reasons for this are discussed in Chapter 6.

7-8 STARS

Kingston

Figure 5.71 below shows that Design 14 is the most cost effective in saving net emissions for the Kingston house, whereas Design 17 is the most cost effective in saving space-conditioning emissions. Design 19 is the least cost-effective design (ranked 28th) in saving net emissions, and Design 28 is the least cost-effective in saving space-conditiong emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 14, whereas the average difference between the cost effectiveness ranking in saving net emsiions and embodied emissions is 9.

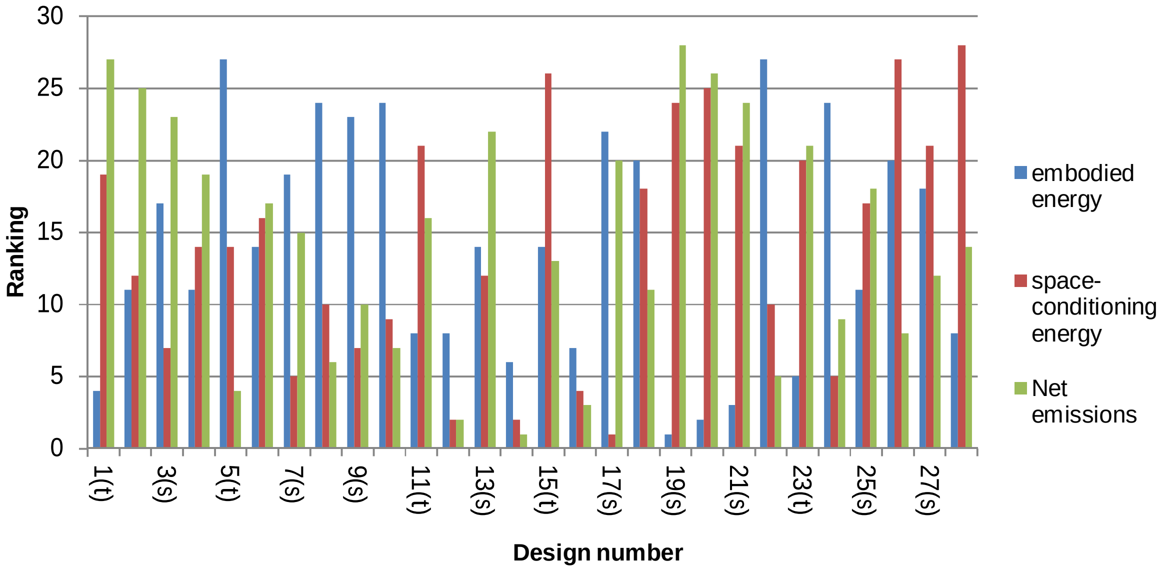


Figure 5.71 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Kingston)

Crimson

Figure 5.72 below shows that Design 16 is the most cost effective in saving net emissions and Design 17 is the most cost effective in saving space-conditioning emissions. Design 7 is the least cost-effective design (ranked 28th) in saving net emissions and Design 28 is the least cost-effective in saving space-conditioning emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 8, whereas the average difference between the cost effectiveness ranking in saving net emissions and embodied emissions is 4.

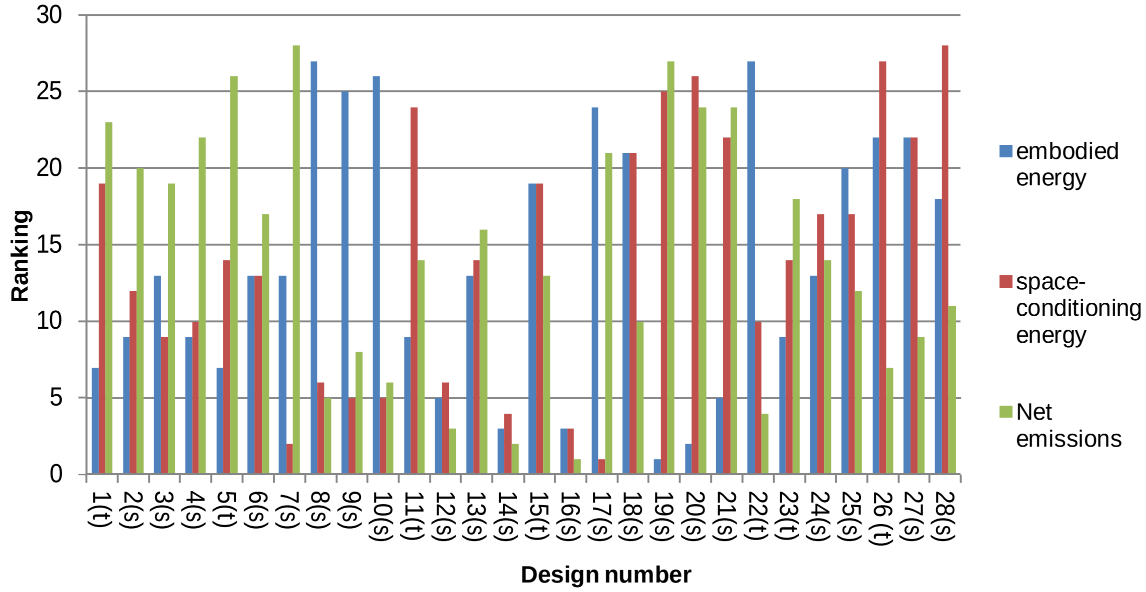


Figure 5.72 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Crimson)

Hickman

Figure 5.73 below shows that for the Hickman house Design 14 is the most cost effective in saving net emissions and embodied emissions and Design 17 is the most cost effective in saving space-conditioning emissions. Designs 4 and 5 are the least cost-effective design in saving net and embodied emissions, respectively, whereas Design 23 is the least cost-effective in saving space-conditiong emissions. The average difference in ranking between a design's cost effectiveness in saving net emissions and space-conditioning emissions is 7, whereas the average difference between the cost effectiveness ranking in saving net emissions and embodied emissions is 5.

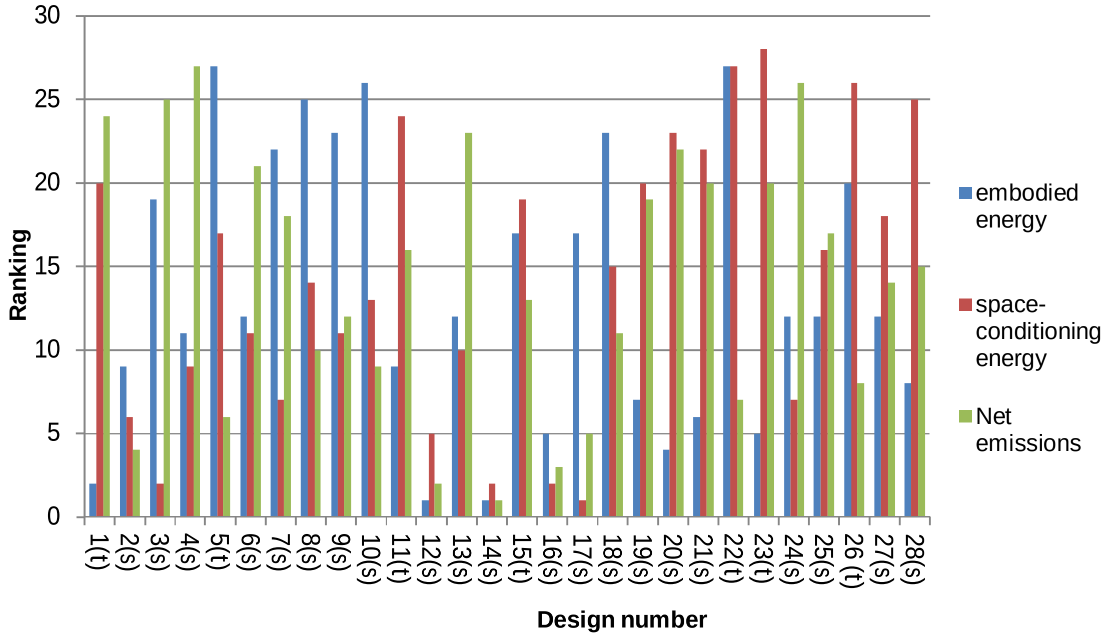


Figure 5.73 – Cost effectiveness comparison: embodied, space-conditioning and net CO_2-e (Hickman)

Summary of the 7-8 star houses

The average difference in the cost effectiveness ranking between savings in net and space-conditioning emissions is greater for designs in the 7-8 star band range than it is for designs in the 5-6 and 6-7 star band ranges. Unlike for 5-6 star and 6-7 star bands, the average difference in the cost effectiveness ranking between savings in net and embodied emissions is less than it is between net and space-conditioning emissions. Overall the average difference in the cost effectiveness ranking between net and space-conditioning and embodied emissions is greater for designs in this star band range. Neither could be used to predict net emissions rankings.

5.7 COST VERSUS SAVINGS IN NET EMISSIONS

The previous sections 5.2 and 5.4 showed the relationship between cost and thermal performance, and cost and embodied energy, respectively. Section 5.5 showed a comparison of the cost effectiveness of designs in avoiding embodied CO_2-e and space-conditioning CO_2-e for each house, and section 5.6 showed a comparison of the cost effectiveness of designs in avoiding embodied CO_2-e, space-conditioning CO_2-e and net CO_2-e for each house.

This section will examine the cost of reducing the net emissions (reduction in space conditioning emissions plus net increase in embodied emissions) of each of the thermal performance improvements for each house in the various star band ranges.

5-6 STARS

Kingston

Figure 5.74 shows that just over 50 % of the designs provide net savings in CO_2-e over a 25 year-period. The remaining designs result in a net increase in emissions and therefore cannot be considered cost-effective; that is, money is spent to comply with a regulation that results in an outcome that is counter the regulation's aim of reducing greenhouse gas emissions. The general trend is that the greater the savings in space-conditioning emissions, the fewer savings in net emissions a design provides. In addition, there is a trend that the more expensive a design, the fewer savings in net emissions it provides. However, there are exceptions to this. For example Designs 11, 12, and 14 provide greater savings in net emissions than some other designs, which provide fewer savings in space-conditioning emissions. It can be seen that a thermal performance improvement costing more than $\$40/m^2$ results in a net increase in emissions. Design 10 provides the fewest savings (or greatest increase) in net emissions of the designs within this star band range. It has high levels of floor, wall and ceiling insulation, resulting in a significant increase in its net embodied energy. Design 2 provides the greatest savings in net emissions, and is also the least expensive design. Its window area was reduced and the wall insulation increased modestly.

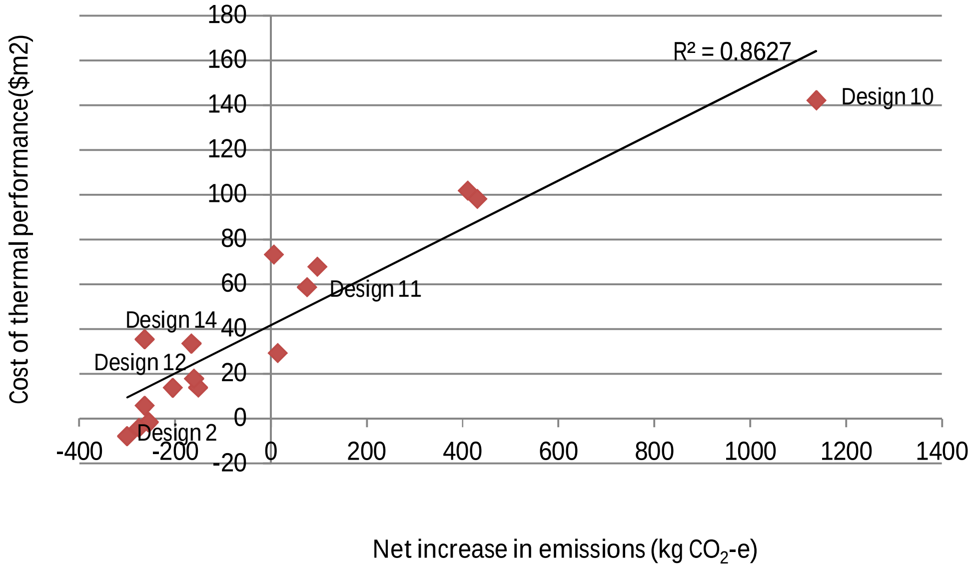


Figure 5.74 – Cost of thermal performance versus net increase in CO_2-e (Kingston 5-6 stars)

Crimson

Figure 5.75 below shows that as for the Kingston house, the general trend is that the greater the savings in space-conditioning emissions a design provides, the fewer savings in net emissions. In general, the more expensive a design, the fewer savings in net emissions it provides although there are exceptions to this. For example, Design 12 is more expensive than four other designs, which all have lower net savings (or greater increase) in CO_2-e.

The two least expensive designs provide the greatest savings in net emissions. They had window areas reduced and the wall and ceiling insulation levels increased modestly. Design 10 is the most expensive design and provides the fewest savings in CO_2-e. It has high levels of floor, wall and ceiling insulation.

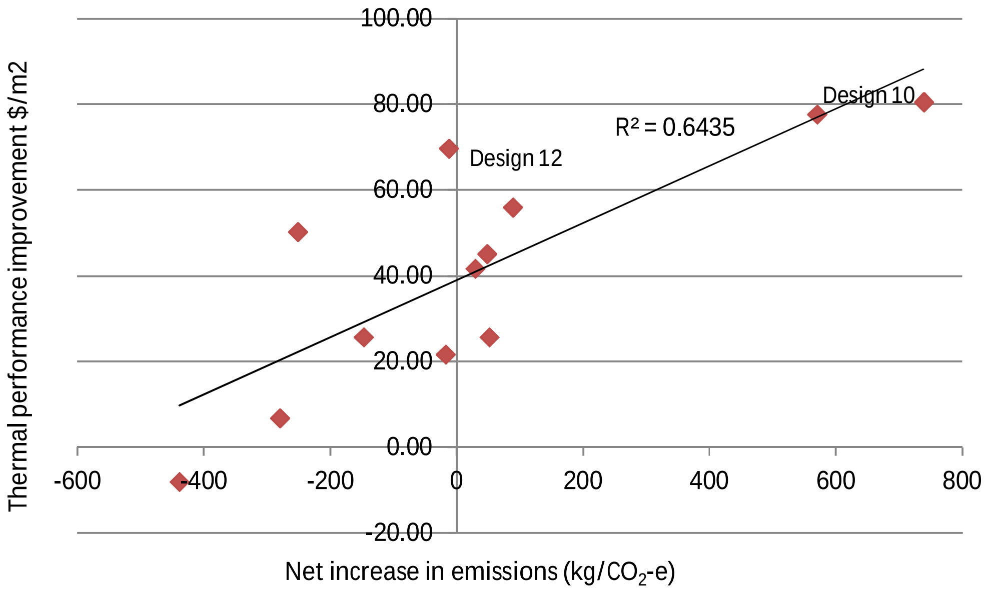


Figure 5.75 – Cost of thermal performance versus net increase in CO_2-e (Crimson 5-6 stars)

Hickman

For the Hickman house (see Figure 5.76 below), the three least expensive designs, (all negative cost) provide the greatest savings in net emissions.

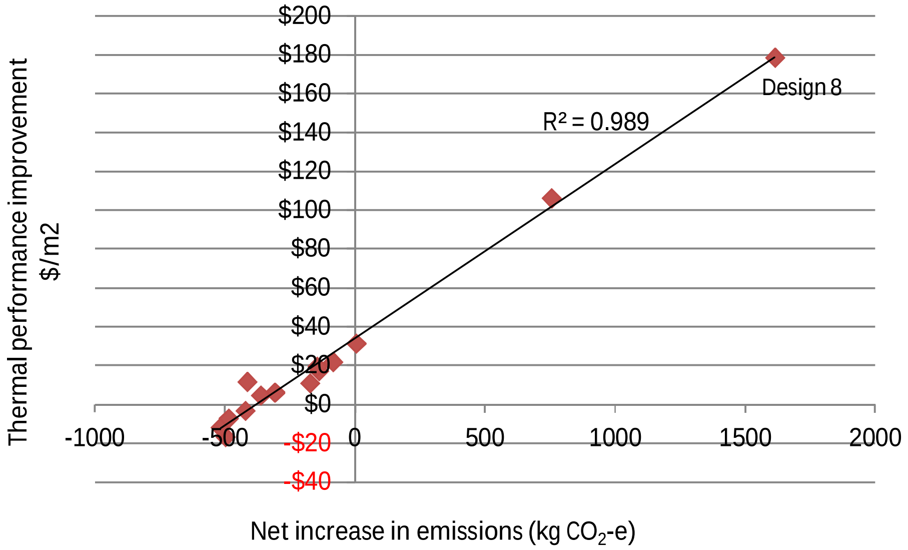


Figure 5.76 – Cost of thermal performance versus net increase in CO_2-e (Hickman 5-6 stars)

The common features of these designs are a reduction in window areas and modest increases in insulation levels. Design 8, which is the most expensive design and provides the fewest savings in net emissions, has high levels of floor (R10), wall (R10) and ceiling (R12) insulation.

6-7 STARS

Kingston

Figure 5.77 shows that while the most expensive designs provide the least savings (or have the greatest increase) in net emissions, the least expensive design results in the fewest net emissions (fewer than the 4-star reference house). Designs that result in fewer net emissions than the Reference House have thermal performance improvements that range in cost between $40/m2 to around $100/m2. The correlation between cost and savings in net emissions is weaker for designs in this star band range than it is for those in the 5-6 star band range.

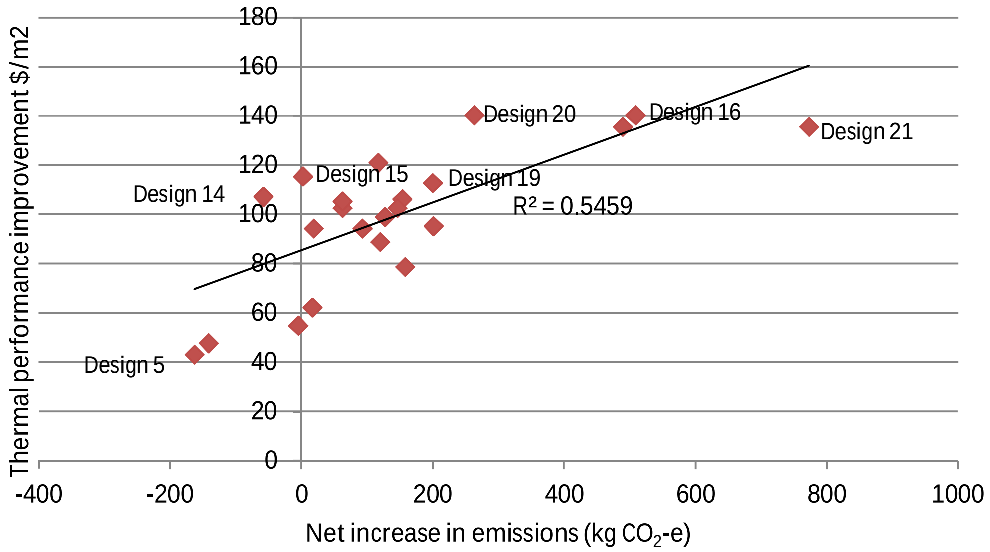


Figure 5.77 – Cost of thermal performance versus net increase in CO_2-e (Kingston 6-7 stars)

Design 5, the least expensive design had its window area reduced, under-slab insulation added and the wall and ceiling insulation increased modestly (R1.0 floor insulation added and wall and ceiling insulation increased to R2.5 and R5.0, respectively). The most expensive, Designs 16 and 20, which are amongst the top four designs which provide the fewest emissions savings, had window areas reduced (by about 50%), those windows were double-glazed, and high levels of floor, wall and ceiling insulation added (wall and ceiling insulation increased to R6.0 and R8.0 respectively). Design 21 provides the least savings in net emissions. It had R8.0 floor insulation added, and the wall and ceiling insulation levels increased to R8.0 and R10.0 respectively.

With the exception of Design 14, any thermal performance improvement that costs more than $\$60/m^2$ results in a net increase in emissions. Design 14 had its window area reduced and windows double-glazed. However, in contrast to other designs that cost about the same, the insulation levels of Design 14 were increased modestly, and tiles replaced carpet in the living/dining room. This results in it having lower embodied emissions than other designs having a similar cost, the extent of which leads to a net savings in CO_2 emissions, rather than a net increase.

Similarly, the costs of Designs 15 and 19 are approximately the same, though Design 15 results in a lower increase in net emissions. Design 15 had its window area reduced and those windows were double-glazed. In addition, its slab thickness was increased, tiles replaced carpet, R3.0 under slab insulation was added, and the wall and ceiling insulation increased slightly. Design 19 has reduced window areas in living/dining room, which are double-glazed, a thicker slab that Design 15, but the same insulation levels. As a result, Design 15 has lower embodied emissions and also provides greater savings in heating/cooling emissions.

Crimson

Figure 5.78 shows that Design 2 provides the greatest savings in net emissions whereas Design 20, the most expensive design provides the fewest savings in net emissions. This is despite the star rating of Design 2 being 0.7 lower than that of Design 20. Both designs have the same glazing area, but Design 20 has a larger area of double-glazing and significantly higher levels of floor, wall and ceiling insulation than Design 2, resulting in it having a much higher net increase in embodied emissions.

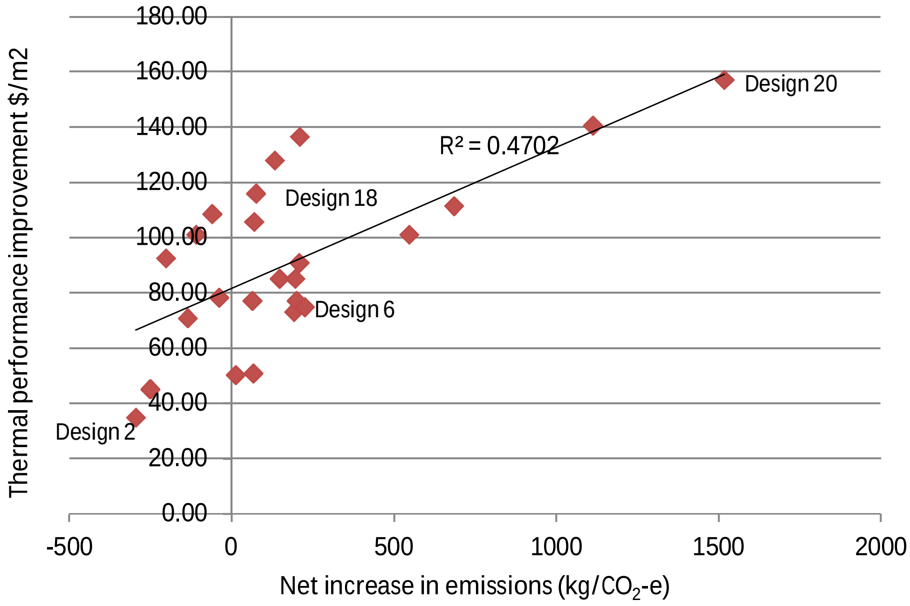


Figure 5.78 – Cost of thermal performance versus net increase in CO_2-e (Crimson 6-7 stars)

There is a cluster of designs with thermal performance improvements costing around \$80/m^2 which save fewer net emissions than six more expensive designs, reversing the overall trend of more expensive designs providing few savings in net emissions than less expensive ones. For example Design 6 is less expensive than Design 18, but it provides fewer savings in net emissions. Both designs have the same glazing area and the same windows are double-glazed and they both have similar levels of floor, wall and ceiling insulation. However, Design 18, a slab-on-ground design, has tiles in lieu of carpet and also has a 0.6 higher star rating than Design 6. Its greater saving in net emissions is the result of its lower increase in embodied emissions (tiles in lieu of carpet) and also its greater saving in space-conditioning emissions (a result of its higher star rating).

Hickman

Figure 5.79 below shows that as for the Kingston and Crimson houses, the most expensive designs provide the least savings in net emissions. However, there are two designs that provide a greater saving in net emissions than the least expensive design. They have a high star rating (at least 6.9 stars) which was achieved at relatively low cost. Each design had the window areas reduced and double-glazed and only modest levels of insulation added (wall and ceiling insulation was increased to R2.5 and R5.0 respectively). The most expensive design had living/dining room windows reduced and double-glazed, and has high levels of floor, wall and ceiling insulation (R8.0, R8.0 and R10 respectively).

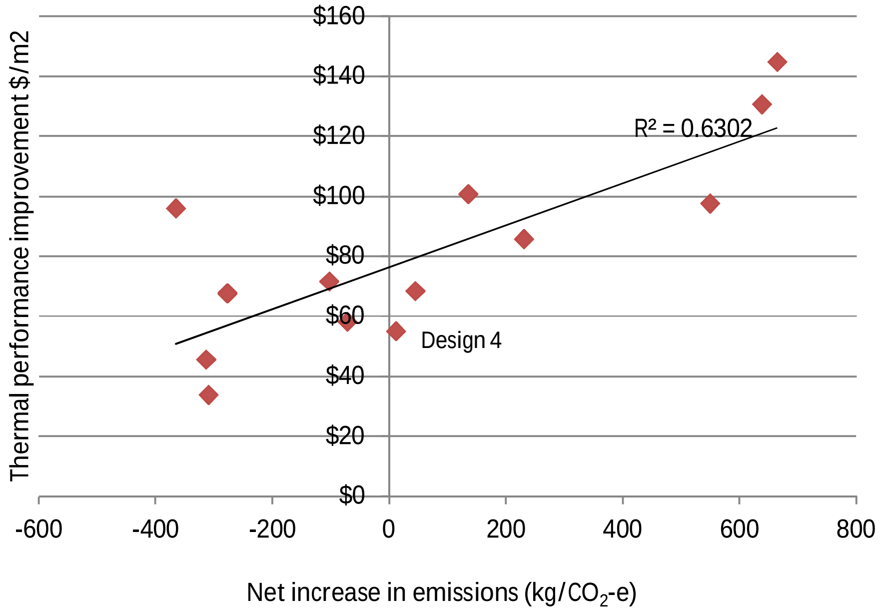


Figure 5.79 – Cost of thermal performance versus net increase in CO_2-e (Hickman 6-7 stars)

In a reversal of the general trend, Design 4 provides fewer savings in net emissions than four designs that are more expensive. The more expensive designs have a similar increase in embodied energy as 4. However they have up to a one star higher rating, resulting in a greater savings in space-conditioning emissions.

7-8 STARS

Kingston

Figure 5.80 shows that only two designs within this star band range provide a net savings in emissions. They have the same moderate insulation levels (R3.0 under-slab, R2.5 wall, and R5.0 ceiling), the same window areas, and tiles in lieu of carpet. Windows in the living/dining and bedrooms were argon-filled double-glazed with a timber frame, which provide a higher level of thermal performance than double-glazed aluminium windows, and have a lower embodied energy. In terms of saving net emissions, they are very cost effective. The tiles in lieu of carpet result in a reduction in embodied energy, contributing to net savings in emissions. The role of tiles in minimizing a design's net emissions has far more to do with their embodied energy being lower than carpet than the thermal performance improvement they provide.

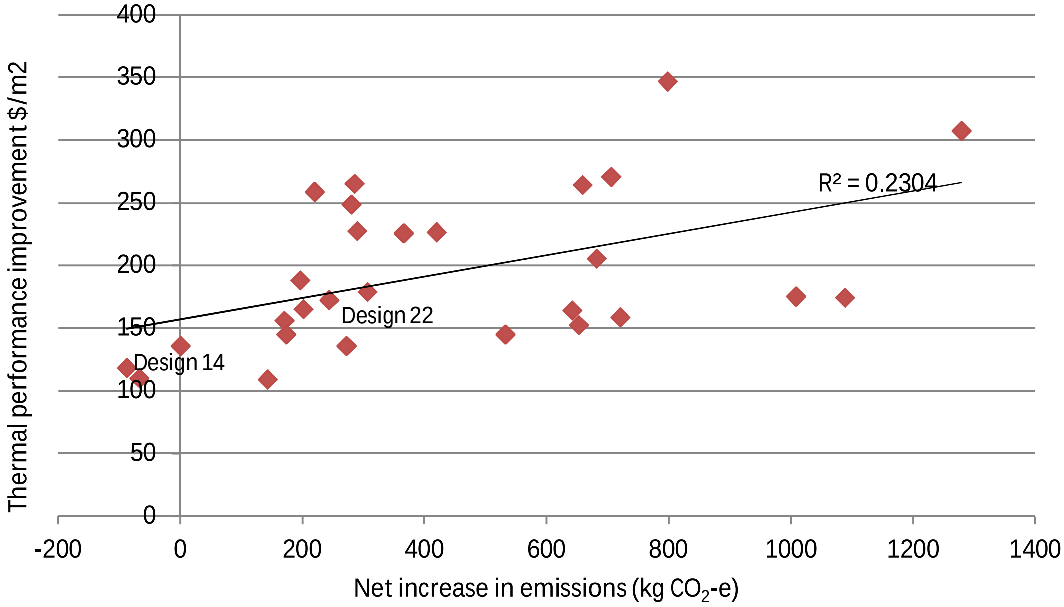


Figure 5.80 – Cost of thermal performance versus net increase in CO_2-e (Kingston 7-8 stars)

The correlation between net emissions saved and cost for designs in this star band range is much weaker than it is for the lower star bands and the most and least expensive designs do not provide the least and most savings in net emissions, respectively. There are cases where designs that cost around the same provide very different savings in net emissions, and cases where the reverse is true.

The main differences between two designs which are similar in cost, but whose net savings in emissions differs significantly, are due to insulation levels and one having tiles in lieu of carpet. For example, Design 22 whose net increase in emissions is greater than Design 14 has much higher levels of insulation and carpet (not tiles), in the living/dining and bedrooms. The higher insulation levels and carpet result in higher embodied emissions while the cost of the higher insulation levels approximates the extra cost of tiles of the other design.

Crimson

Figure 5.81 shows that as for the Kingston house the correlation between cost and net savings in emissions is lower for designs in this star band range than it is for the 5-6 and 6-7 star band ranges. The least expensive design does not provide a positive net savings in emissions, while three more expensive designs do.

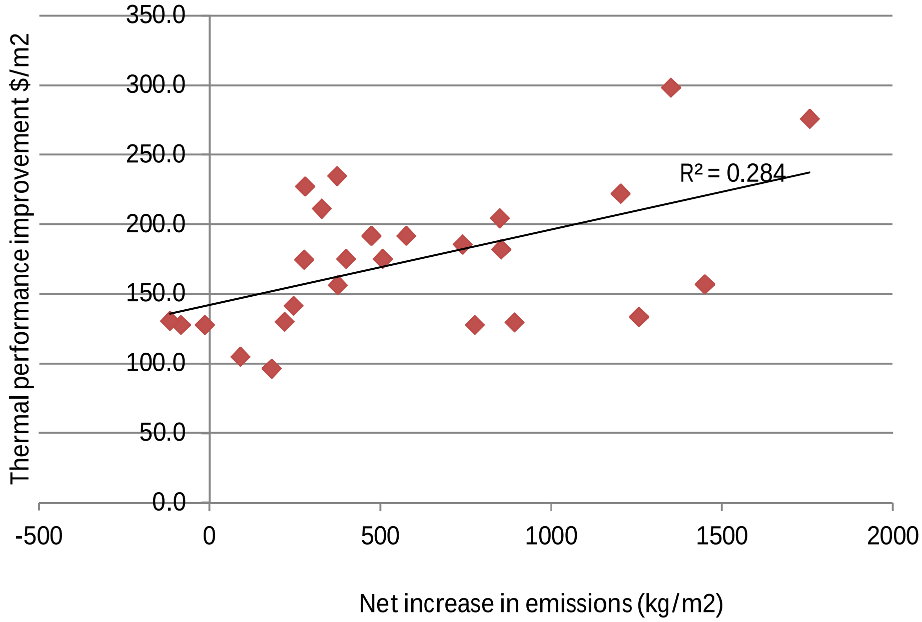


Figure 5.81 – Cost of thermal performance versus net increase in CO_2-e (Crimson 7-8 stars)

The design that provides the greatest savings in net emissions had the living/dining and bedroom windows reduced, and those windows are timber-framed and double-glazed. Its slab thickness was increased to 150mm, R3 under-slab insulation added and the wall and ceiling insulation increased slightly, and tiles replaced carpet. Relative to other designs, these are low embodied emissions changes that also lead to good thermal performance (7.6 stars). As for other houses in this and lower star band ranges, the design that provides the least savings in net emissions has very high levels of floor, wall and ceiling insulation.

Hickman

A larger number of designs provide a net savings in emissions for the Hickman house than the Kingston and Crimson houses in this star band range. Figure 5.82 shows that while the least expensive design, Design 2, does not provide the most savings in net emissions, the most expensive design, Design 32, provides the least. Design 2 had the living/dining and bedroom windows reduced, and those windows were double-glazed. R1 under-slab insulation was added, as well as high levels of wall and ceiling insulation. The most expensive has the same glazing area as least expensive design and the same windows are double glazed. Its added expense and reduced savings in net emissions is attributable to its high levels of floor, wall and ceiling insulation.

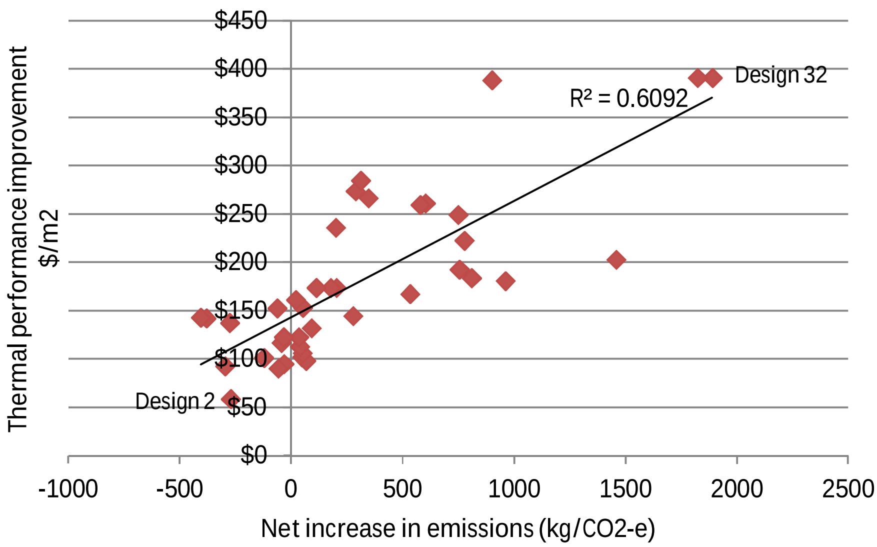


Figure 5.82 – Cost of thermal performance versus net increase in CO_2-e (Hickman 7-8 stars)

Summary

For each house in each of the star band ranges, the overall trend is that the more expensive a design is, the fewer savings in net emissions it provides. Generally, as a design's thermal performance increases, its embodied emissions increase as well, which can lead to the point where savings in space-conditioning emissions are outstripped by the increase in embodied emissions. For each house in the 7-8 star band range, a majority of thermal performance improvements actually result in an increase in net emissions. In terms of avoiding CO_2-e these designs cannot be considered cost effective.

5.8 SENSITIVITY ANALYSIS

This section reports the results of separate sensitivity analyses that were undertaken to determine the effect on the results of changes in the orientation of the houses, the type and efficiency of space-conditioning appliances, and the emissions intensity of electricity.

5.8.1 Orientation

The results reported in this Chapter were for the Reference Houses, which were orientated to optimize thermal performance. This section examines the affect orientation has on thermal performance (star rating), while the implications of this on cost and embodied energy are discussed in Chapter 6. A timber-floor and slab-on-ground design that achieved a low star rating and a timber-floor and slab-on-ground design that achieved a high star rating for the Kingston house in each star band range, that is, a total of 12 designs, were modelled in three additional orientations: East, South and West[15]. This was repeated using the same designs for the Crimson and Hickman houses.

5-6 STAR

Tables 5.29 – 5.32 show the slab-on-ground and timber-floor designs that achieved a rating of between 5 and 6 stars for the Kingston Reference House, and their star rating in

[15] The optimal orientation of each Reference house varied slightly, with a majority of glazing in living/dining rooms of each house orientated between NE and NW. While the changes in orientation are reported here as East, South and West, they are 90°, 180° and 270° changes from the optimal orientation of each house.

three other orientations. It can be seen that the thermal performance of the Kingston and Crimson designs (both the timber floor and slab-on-ground design) are less sensitive to changes to orientation than the Hickman house, which performs much better thermally when facing north (that is the living/dining room) than in it does for other orientations. For the Hickman house, the timber-floor designs are less sensitive to changes in orientation than the slab-on-ground designs.

Table 5.29 - Effect of orientation on star rating (low 5 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**5.1**	4.8	4.9	5	5.0
Crimson	**4.9**	4.6	4.9	4.8	4.8
Hickman	**5.7**	4.7	5.4	5.1	5.2

Table 5.30 - Effect of orientation on star rating (high 5 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**5.9**	5	5.4	5.4	5.4
Crimson	**5.9**	5.4	6.1	5.3	5.7
Hickman	**6.9**	5.2	5.4	6	5.9

Table 5.31 - Effect of orientation on star rating (low 5 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**5.1**	4.6	4.8	5	4.9
Crimson	**4.7**	4.5	4.8	4.4	4.6
Hickman	**4.9**	3.9	4.3	4.3	4.4

Table 5.32 - Effect of orientation on star rating (high 5 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**5.9**	5.3	5.7	5.6	5.6
Crimson	**5.9**	5.4	5.8	5.2	5.6
Hickman	**6.2**	4.9	5.3	5.4	5.5

6-7 STARS

Tables 5.33 –5.36 show the slab-on-ground and timber-floor designs that achieved a rating of between 6 and 7 stars for the Kingston Reference House when orientated north and their star rating in three other orientations.

As was the case for designs that achieved a rating of between 5 and 6 stars, the thermal performance of the Kingston and Crimson designs are less sensitive to changes in orientation than the Hickman designs, with the Hickman slab-on-ground designs being more sensitive than timber-floor designs.

Table 5.33 - Effect of orientation on star rating (low 6 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**6.2**	5.4	5.8	5.8	5.8
Crimson	**6**	5.4	6.2	5.3	5.7
Hickman	**6.9**	5.4	6.7	6.1	6.3

Table 5.34 - Effect of orientation on star rating (high 6 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**6.9**	5.9	6.4	6.4	6.4
Crimson	**6.9**	6.4	7.1	6.3	6.7
Hickman	**7.6**	5.9	6.3	6.9	6.7

Table 5.35 - Affect of orientation on star rating (low 6 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**6.1**	5.4	5.8	5.8	5.8
Crimson	**5.8**	5.3	5.7	5.1	5.5
Hickman	**6**	5	5.3	5.4	5.4

Table 5.36 - Effect of orientation on star rating (high 6 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**6.9**	6.3	6.7	6.6	6.6
Crimson	**6.9**	6.2	7.2	6.2	6.6
Hickman	**7.1**	5.9	6.4	6.3	6.4

7-8 STARS

Tables 5.37 –5.40 show the slab-on-ground and timber-floor designs that achieved a rating of between 7 and 8 stars for the Kingston Reference house when optimally orientated and their star rating in three other orientations. The degree to which the thermal performance of the houses is sensitive to orientation remains generally the same as it was for the lower star band ranges. However, for the Hickman house, the slab-on-ground designs are even more sensitive to orientation than the timber-floor designs than they were in the lower star band ranges.

Table 5.37 - Effect of orientation on star rating (low 7 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**7.1**	6.4	6.8	6.7	6.8
Crimson	**6.9**	6.6	6.9	6.4	6.7
Hickman	**7.3**	6.1	6.4	6.4	6.6

Table 5.38 - Effect of orientation on star rating (high 7 star timber floor house)

	North (Reference)	South	East	West	Average
Kingston	**7.9**	7.3	7.6	7.6	7.6
Crimson	**7.8**	7.7	8	7.6	7.8
Hickman	**8.2**	7.4	7.6	7.6	7.7

Table 5.39 - Effect of orientation on star rating (low 7 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**7.1**	5.9	6.3	6.6	6.5
Crimson	**7.1**	6.3	7.4	6.2	6.8
Hickman	**8.1**	5.9	6.3	7.2	6.9

Table 5.40 - Effect of orientation on star rating (high 7 star slab-on-ground house)

	North (Reference)	South	East	West	Average
Kingston	**7.9**	6.9	7.3	7.4	7.4
Crimson	**7.8**	7.6	7.9	7.4	7.7
Hickman	**8.9**	7.2	7.4	8.3	8.0

The implications that changes in orientation have on the capital costs of improving thermal performance are discussed in Chapter 6.

5.7.2 Efficiency of heating appliances

Space-conditioning and net emissions were calculated on the assumption that electric heating appliances were a relatively inefficient 100% (the case for resistive heaters). More efficient electric heating appliances are available, such heat pumps which are approximately 350% efficient. While electric heating appliances have become far more efficient in recent years due to technological improvements, in comparison improvements in the efficiency of gas appliances have lagged behind.

A sensitivity analysis was undertaken to determine the effect a more efficient electric heating appliance (350% versus 100%), and the use of gas heating, have on the net savings in CO_2 emissions. (Note: the embodied emissions and capital costs of appliances were not taken into account). In the case of electric heating it was assumed that heat pump efficiency remains a constant 350% (that is, a Coefficient of Performance of 3.5) over the modelling period (25 years), although slight improvements in future years could be expected. In the case of gas heating it was assumed that a combination of space and ducted heating is used and that efficiency remains a constant 70% over the modelling period.[16]

Figures 5.83 - 5.85 below show the base case results (100% electric heating) for net savings in CO_2 emissions compared with more efficient electric as well as gas heating. Sensitivity was undertaken for each house in the 6-7 star band range.

[16] It clear from these relative appliance efficiencies that 1kWh (=3.6MJ) of electricity at the meter requires 18MJ of gas (=3.6x3.5/0.7) to deliver the same heating service in MJ. The failure of the gas appliance industry to compete on efficiency means that gas no longer has the environmental edge over electric appliances it once did.

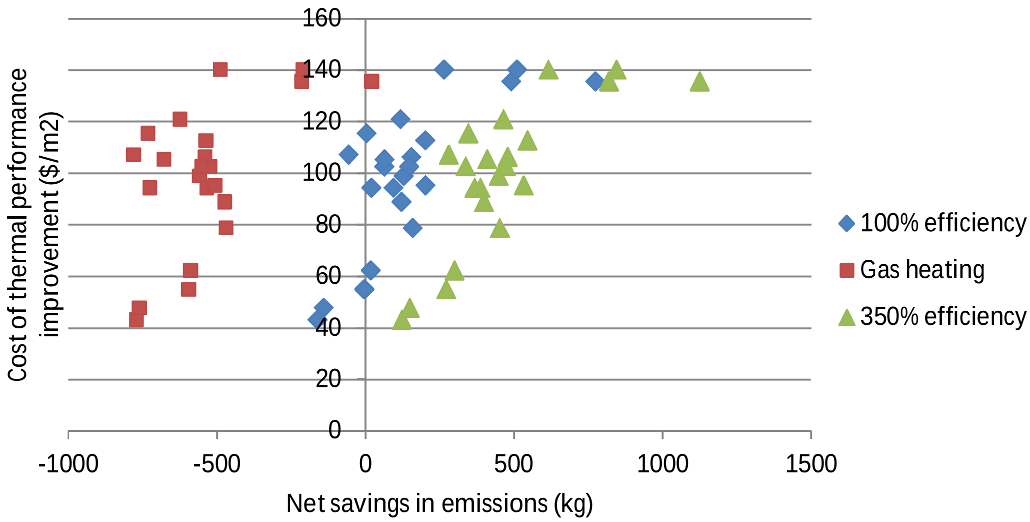


Figure 5.83 –Net savings in emissions (Kingston 6-7 star)

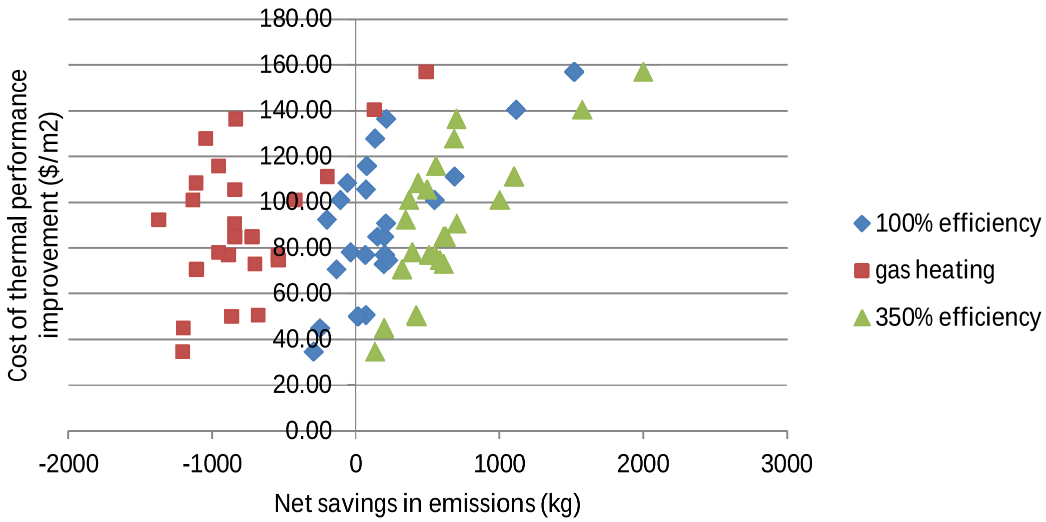


Figure 5.84 –Net savings in emissions (Crimson 6-7 star)

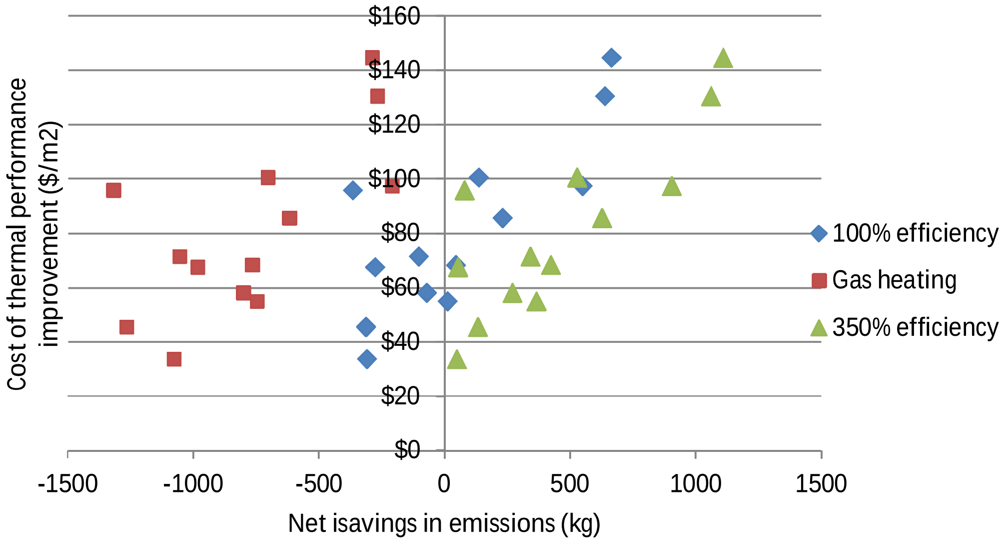


Figure 5.85 –Net savings in emissions (Hickman 6-7 star)

The figures above show that if more efficient electric heating is used, there are fewer savings in net CO_2 emissions as compared to the base case results (that is, more efficient heating results in a greater increase in net emissions). This result is explained by the relative proportions of embodied and space conditioning emissions that make up the net emissions of houses with different heating systems. Figure 5.86 below shows how these proportions can vary. When more efficient electric heating is used, there are fewer space-conditioning emissions to save, while the embodied emissions remain the same irrespective of appliance efficiency.

The figures above show that if a heat pump (350% efficiency) is used, improving the thermal performance of the Reference Houses to achieve a rating of between 6 and 7 stars will not result in any savings in CO_2 emissions; emissions actually increase for each house because the embodied emissions of the thermal performance improvement are much more significant.

On the other hand if gas heating is used, the net savings in CO_2 emissions increases as compared to the base case results. The CO_2 emissions associated with gas space heating as a proportion of net emissions is higher (and embodied emission lower) than it is for the base case. The figures above show that if gas heating is used, improving the thermal performance of the Reference houses to achieve a star rating of between 6 and 7 stars results in a decrease in CO_2 emissions. In terms of the cost effectiveness of thermal performance improvements in saving CO_2 emissions, the type and efficiency of heating systems is obviously a significant factor.[17]

Notwithstanding differences in net emissions savings, the *total* net emissions associated with a house that uses gas heating would be higher than if the same house used relatively inefficient (100% electric heating), whereas they would be lower if more efficient electric heating was used (refer to Figure 5.86 below). Therefore, in terms of saving CO_2 emissions it may be more cost effective to improve the efficiency of a house's heating appliances than to improve its thermal performance. Figure 5.87 below makes clear how this may be the case. The Kingston house with a 5-star rating when using electric heating (100% or 350% efficiency) produces fewer CO_2 emissions than if it had 7-star rating and used electric heating (100% efficient) or gas heating.

[17] While the cost effective ratios of thermal performance measures in saving space-conditioning emissions and net emissions would change as a result of improving appliance efficiency, the rankings of measures would remain the same. Therefore the cost effectiveness of measures reported in the results would not change irrespective of appliance efficiency.

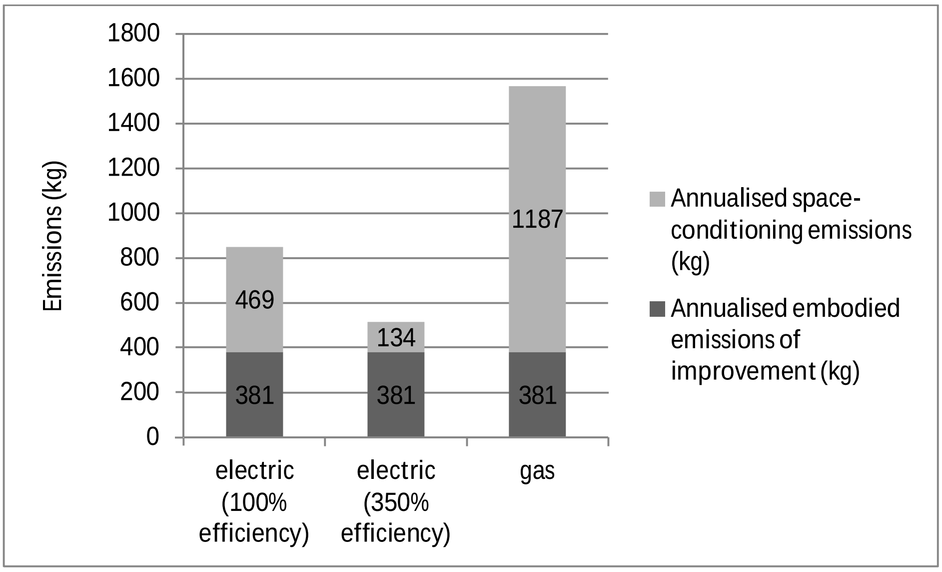


Figure 5.86- The influence of heating appliance type on net emissions[18]

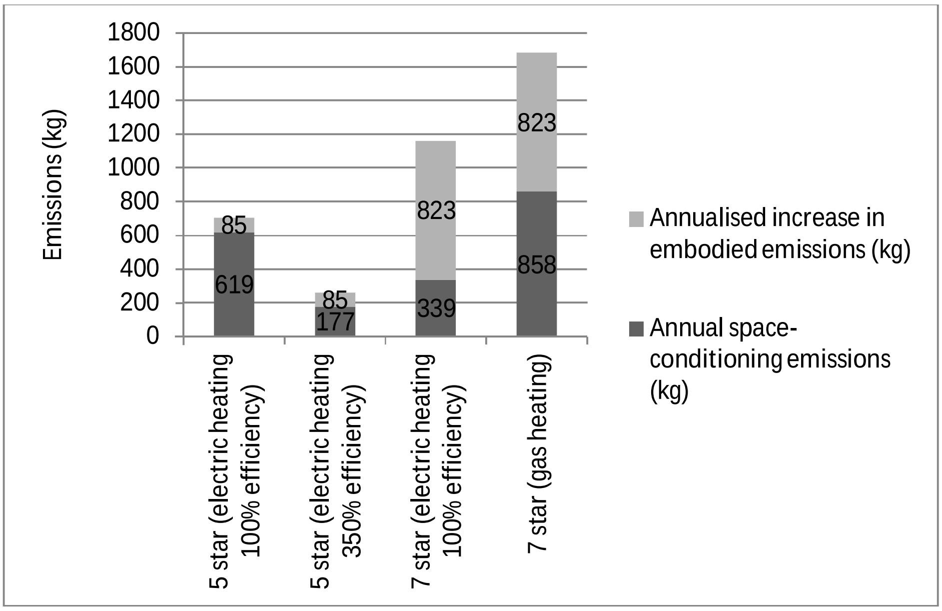


Figure 5.87 – Net emissions of a 5 star versus a 7 star design (Kingston house)

5.7.3 Emissions intensity of electricity

The results are based on the houses being located in Tasmania where the emissions intensity of purchased electricity is much lower than it is in mainland states. A sensitivity analysis was done whereby the net increase in emissions was calculated using the

[18] These results are based on a 6 star Kingston house.

emissions intensity of purchased electricity in Victoria.[19] Figure 5.88 below shows the difference in the net increase in emissions for the Kingston house (rating between 6 and 7 stars) between the two locations where electric heating (100% efficiency) is used. Figure 5.88 shows that in Victoria, increasing the thermal performance of the Reference house to achieve a rating of between 6 and 7 stars leads to a considerable reduction in net emissions. By comparison in Tasmania, there are only several designs that have lower net emissions than the Reference House.[20]

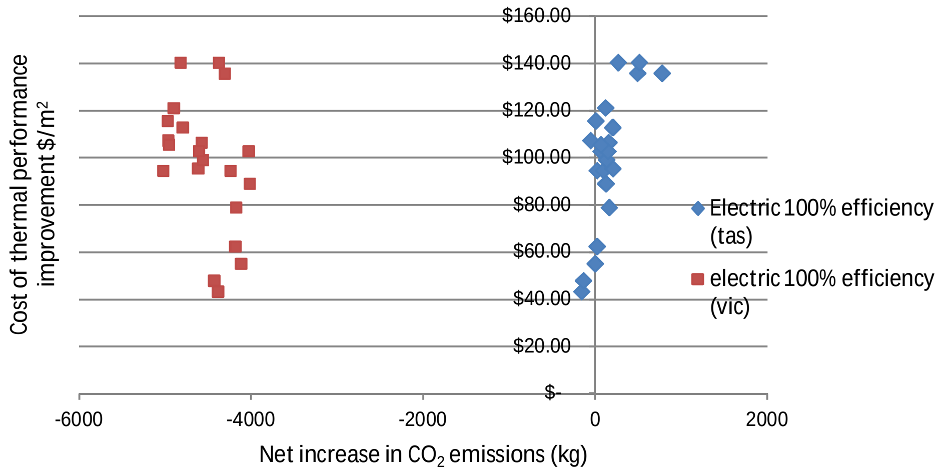


Figure 5.88- Difference in net increase in emissions between Victoria and Tasmania

5.9 CONCLUSION

The results revealed that for each house, numerous design strategies can achieve thermal performance within a certain star band range, and that the correlation between cost and thermal performance in each star band range is not strong. The cost effectiveness of these designs in saving space-conditioning emissions varies for each house, with the variability between houses increasing as higher levels of thermal performance are sought. For all houses it is considerably less expensive for the slab-on-ground houses to achieve the lower star band ranges than the timber-floor houses. However, this gap in cost narrows for the higher star band ranges.

[19] 1.22 kg CO_2-e /kWh in 2008
[20] This based on the assumption that the heating and cooling loads are the same in the two locations *i.e.* the climates are the same or very similar.

The results also revealed that the correlation between embodied energy and thermal performance was not strong for all houses, for either floor type, and in all star band ranges. This would indicate that the increase in embodied energy from a particular thermal performance improvement does not necessarily provide an indication of the level of thermal performance they achieve relative to each other. The difference in the increase in embodied energy between slab-on-ground designs and timber floor houses narrows as the level of thermal performance increases.

The correlation between cost and embodied energy in the lower star band ranges is generally quite strong. However this weakens as thermal performance increases. The variability in ranking of a design's cost effectiveness in minimizing the increase in embodied emissions increases between the three houses as the level of thermal performance increases.

It was also evident that what is cost effective in reducing space-conditioning emissions is not necessarily cost effective in minimizing the increase in embodied emissions, or net emissions. The factors that influence these relationships are discussed in Chapter 6.

An analysis showed that the thermal performance of the Kingston and Crimson designs (both the timber floor and slab-on-ground design) are less sensitive to changes to orientation than the Hickman house in each star band range. The Hickman house performs much better thermally when facing north, the slab-on-ground designs becoming more sensitive to orientation than the timber-floor designs in the highest star band range.

Finally, the sensitivity analysis revealed that heater type and efficiency has a significant bearing on whether thermal performance improvements will result in a net savings in emissions as does the emissions intensity of purchased electricity.

CHAPTER 6 – DISCUSSION

6.1 INTRODUCTION

The cost effectiveness of thermal performance improvements in reducing space-conditioning emissions (one of the goals of the Australian government's energy efficiency regulations for housing), minimizing the increase in embodied emissions, and in saving net emissions for three Reference houses, with two floor types, were determined in Chapter 5. The need to undertake such analyses was based on a literature review, which showed that cost effectiveness studies of thermally efficient houses neglect embodied energy and associated emissions. The results and their significance will be discussed in this chapter.

The first part of the discussion addresses thermal performance and cost; the second part embodied energy and cost; and the third part net emissions and cost. Finally, there is a discussion about the optimum levels of thermal performance that meet the objectives of the Building Code of Australia.

6.2 THERMAL PERFORMANCE AND COST

6.2.1 Materials and methods

Thermal performance improvements are interdependent. In many cases, the improvement in thermal performance that results from combining a number of measures exceeds the aggregate improvement of those measures applied individually. This had implications for the overall cost of achieving a certain star rating. Generally, the more variations made to a design, the less expensive it is to achieve a certain level of thermal performance.

The individual measures and their relationship with each other in terms of optimizing cost and thermal performance are discussed below.

Insulation

There is a point beyond which the effectiveness of any further increases to the insulation levels of one part of the building envelope (either to the floor, wall or ceiling) quickly diminishes if the insulation levels of the other parts of the envelope remain unchanged. It is more cost effective to increase insulation levels to all parts of the envelope modestly than to increase one part significantly. However, increasing the insulation levels of the whole building envelope will also only continue to provide cost effective thermal performance benefits up to a point. Beyond that only slight increases in thermal performance (star rating) are achievable. This is demonstrated in Figures 6.1- 6.3 below, which show that as insulation levels are increased incrementally the increase in thermal performance diminishes while costs increase exponentially. The five incremental increases to insulation levels (to the Reference Houses) are shown in Table 6.1.

Table 6.1- Incremental increases in insulation levels

Timber floor	Slab-on-ground
1.Wall R1.5, Ceiling R5.0 (Reference house)	1. Wall R1.5 Ceiling R5.0 (Reference house)
2. Wall R2.5, Ceiling R5.0	2. Wall R2.5, Ceiling R5.0
3. Floor R1.5, Wall R2.5, Ceiling R5.0	3. Floor R1.0, Wall R2.5, Ceiling R5.0
4. Floor R2.5, Wall R4.0, Ceiling R6.0	4. Floor R2.0, Wall R2.5, Ceiling R6.0
5. Floor R4.0, Wall R6.0, Ceiling R8.0	5. Floor R3.0, Wall R6.0, Ceiling R8.0
6. Floor R6.0, Wall R8.0, Ceiling R10.0	6. Floor R3.0, Wall R8.0, Ceiling R10.0

For the Kingston and Crimson houses, it can be seen that the improvement in thermal performance from incremental increases in insulation diminishes sharply beyond 4.5 to 5.0 stars. The effect is the same for the Hickman house, but at slightly higher star ratings.[21]

[21] The graphs only show changes in star rating (and cost) from varying insulation levels. Higher star ratings can be achieved with these insulation levels in combination with other thermal performance improvements. However, the effect of diminishing returns remains the same.

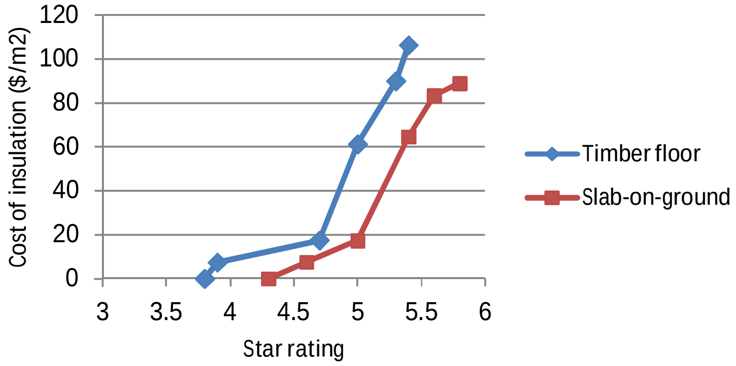


Figure 6.1 – Cost of incremental increase insulation versus star rating improvement (Kingston)

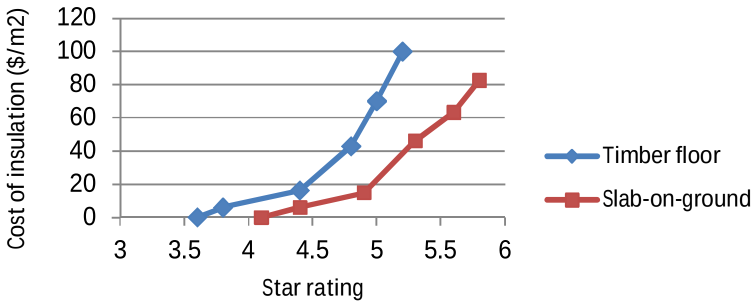


Figure 6.2 - Cost of incremental increase insulation versus star rating improvement (Crimson)

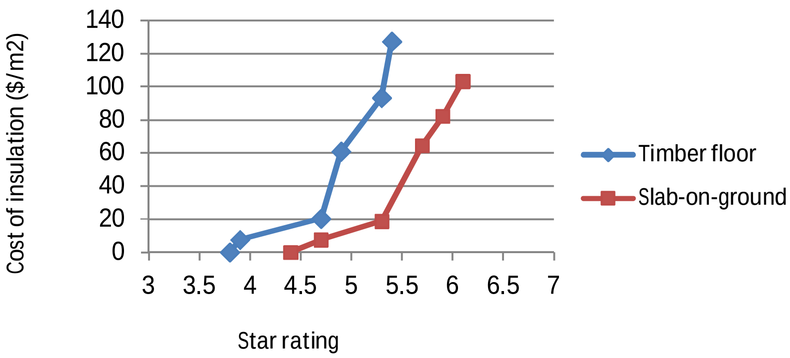


Figure 6.3 - Cost of incremental increase insulation versus star rating improvement (Hickman)

For timber floor houses the optimum insulation levels to achieve 7-8 stars cost effectively, in combination with other design modifications, is around R3.0 floor insulation, R2.5 wall insulation, and R5.0 ceiling insulation. By way of comparison, these insulation levels provide a similar level of thermal performance, without other design modifications, as R8.0 floor insulation, R8 wall insulation and R10 ceiling insulation.

For slab-on-ground houses, the optimum insulation level to achieve 7-8 stars most cost effectively is around R2.0 floor insulation, R2.5 wall insulation, and R5.0 ceiling insulation. As for the timber floor houses, 7-8 stars could only be achieved with these insulation levels if other design modifications are made, which included a reduction in glazing area.

Reducing glazing areas and therefore avoiding the need for significantly higher insulation levels can achieve high levels of thermal performance using typical building techniques. For project homes the only departure from common practice would be the installation of floor insulation. As discussed previously, for timber floor houses in particular, adding floor insulation leads to significant improvements in thermal performance and, apart from no or negative cost improvements, it is the most cost effective first measure that can be taken in improving the star rating of the Reference Houses. However, insulating timber floors is not common practice in Australia as minimum thermal performance standards have not required it. Another obstacle to its more widespread use seems to be a perception by designers and builders that double-glazing is the most effective first step in improving the thermal performance of a 4-5 star timber floor house. However, for timber floor brick veneer houses, insulating the floor can be both cheaper and provide a higher level of thermal performance than double-glazing the windows of the conditioned zones. This was true for each of the houses studied. Without floor insulation, other thermal performance improvements do not realize their full potential. For timber floor houses that achieve a star rating of between 5 and 6 stars, adding R1.5 floor insulation gave the same level of thermal performance as modest increases in the wall and ceiling insulation of the slab-on-ground designs, all else being equal.

Windows

The most cost effective designs in improving thermal performance to achieve any of the star band ranges involved reducing window sizes. Smaller windows both reduced construction cost and increased thermal performance.

Figures 6.4 - 6.6 below show the increase in star rating and the resulting reduction in construction cost for each window area reduction modelled, for each of the houses. The increase in star rating is relative to the slab-on-ground Reference Houses. It can be seen that each change results in a greater increase in star rating for the Hickman house.

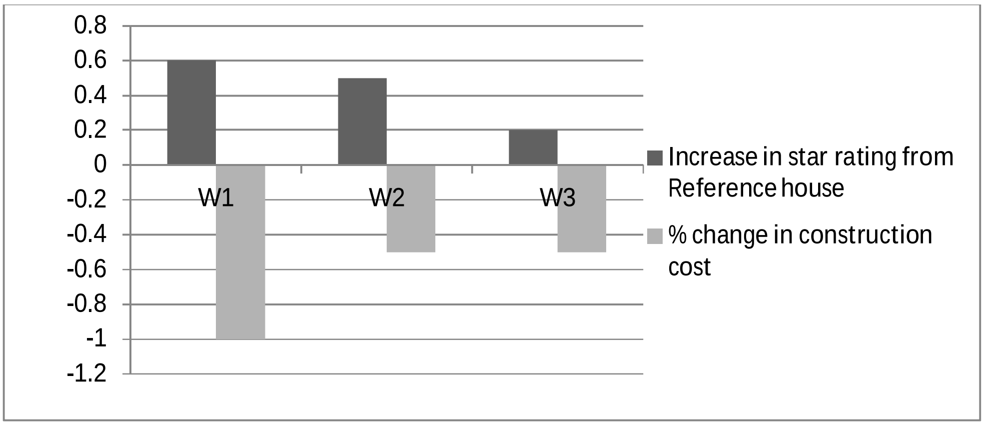


Figure 6.4 – Star rating improvement and change in construction cost from reducing window areas (Kingston)

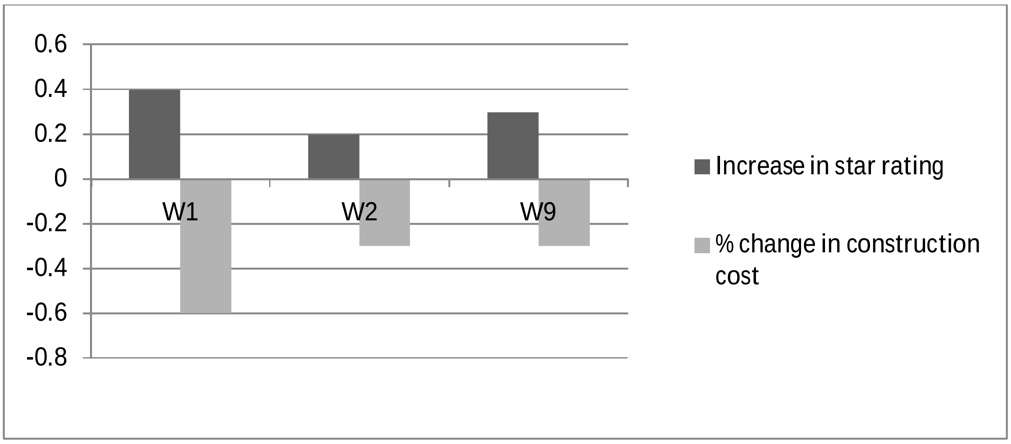


Figure 6.5 – Star rating improvement and change in construction cost from reducing window areas (Crimson)

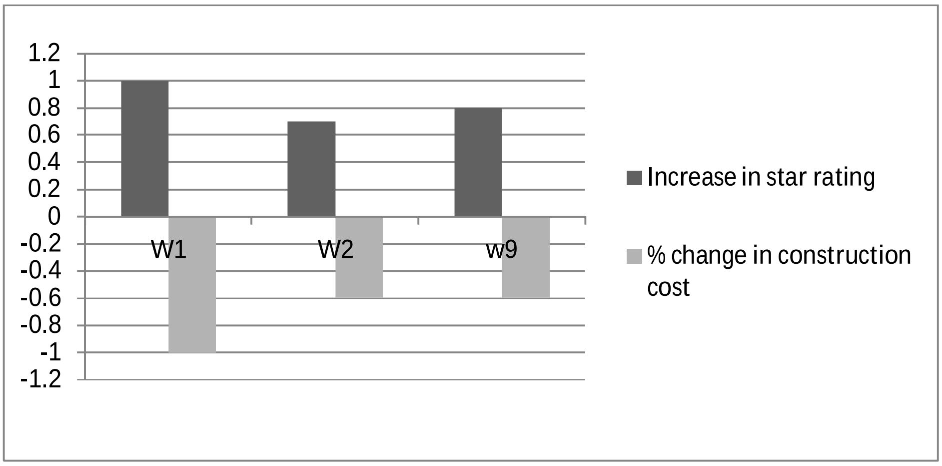


Figure 6.6 – Star rating improvement and change in construction cost from reducing window areas (Hickman)

While windows were not reduced to a size that would compromise views or natural light, their level of market acceptance is uncertain. However, in terms of optimizing cost and thermal performance, windows sizes of standard project homes are too large. In the case of the houses used for this study, this was true for all windows, irrespective of their orientation.

Window frame

The choice between aluminium (single or double-glazed) and timber-framed windows affects a design's cost effectiveness in achieving a certain star rating. Timber-framed windows perform much better thermally than standard aluminum frames, leading to higher star ratings. Even single-glazed timber-framed windows performed at least as well thermally as double-glazed aluminium thermally unbroken windows. Figures 6.7- 6.9 below compare the cost and thermal performance of two windows types for each of the Reference Houses. It can be seen that switching (all windows) from aluminium single-glazed windows to timber-framed windows which are single-glazed is less expensive than switching to double-glazed aluminium windows in the living/dining and bedrooms. In the case of the Hickman house, the timber-framed windows actually provide a greater improvement in star rating than double-glazed aluminum windows.

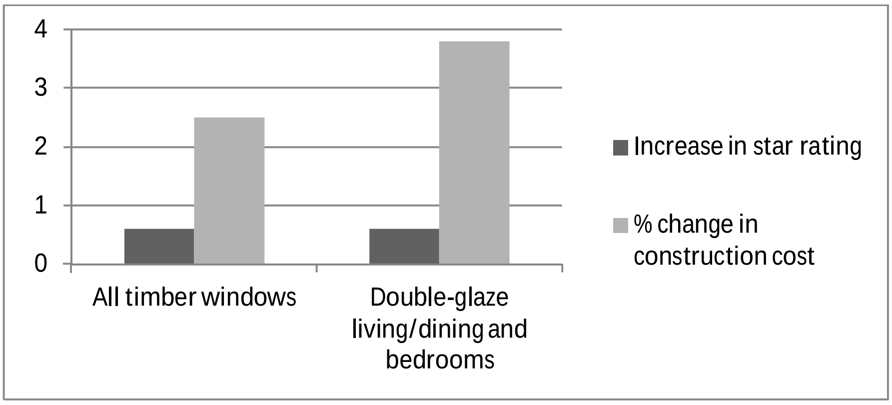


Figure 6.7 - Comparison of cost and thermal performance between window types (Kingston)

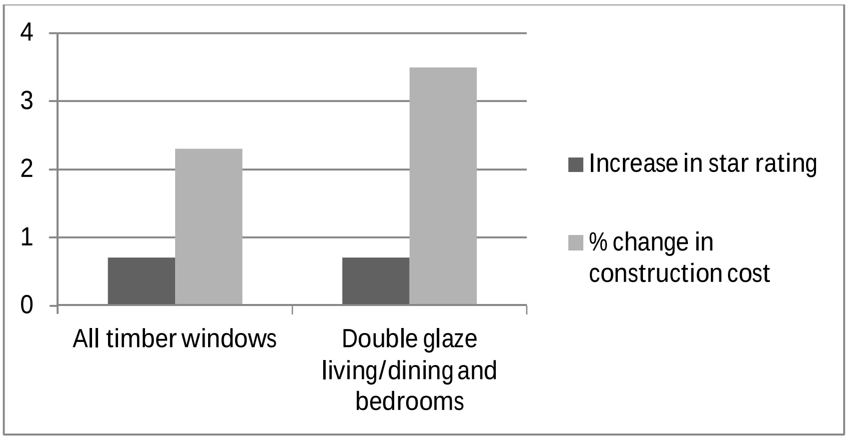


Figure 6.8 – Comparison of cost and thermal performance between window types (Crimson)

Figure 6.9 - Comparison of cost and thermal performance between window types (Hickman)

For designs with a 5-6 star rating, switching from single-glazed aluminium to single-glazed timber frames improved their thermal performance by approximately 0.7 stars. The higher a design's star rating the more cost effective is the switch from aluminium thermally unbroken frames to timber frames. In combination with other improvements, changing a design's window frames from aluminium to timber provided a very similar level of thermal performance as approximately doubling R3 floor, R2.5 wall and R5 ceiling insulation, but for less cost.

Single, double and triple glazing

Triple-glazed windows are very expensive and provide very little thermal performance improvement over double-glazed windows (of the same frame type), making them cost ineffective for the Tasmanian climate. Designs with triple-glazed windows were amongst the least cost effective for each house. This is unsurprising given that triple-glazing is currently a niche product in Australia, and therefore expensive. Although the cost of triple-glazing is likely to fall as its use increases, the rate at which it falls is unlikely to be as rapid as that of double-glazing. Consequently, for the foreseeable future triple glazing is likely to remain a cost ineffective method for improving thermal performance. On the other hand, double-glazed argon filled windows provide a very similar level of improvement to a design's thermal performance as triple-glazing. Since they are significantly cheaper than triple-glazing they are much more cost effective. However in some Scandinavian countries, triple-glazing is cost effective. This is because the extreme cold temperatures make the thermal performance improvement of triple- over double-glazing significant and also because there is very little difference in cost between the window types.

To achieve a rating of between 5 and 6 stars, tradeoffs between glazing area and double-glazing could be made. High 5 star ratings (and even 6 star ratings for the Hickman house) were achieved without the need to double-glaze any windows. However, higher star ratings could not be achieved without at least double-glazing the living/dining rooms. Instead of double-glazing bedroom windows to further improve thermal performance, extra insulation to all parts of the building envelope could be added. However, the levels of insulation required made this option more expensive than double-glazing.

Weatherstripping windows

Weatherstripping windows is a cost effective method to improve a house's thermal performance. The thermal performance benefit weatherstripping provides increases as a house's star rating increases, and therefore so does its cost effectiveness. For example, weatherstripping the windows of the 4-star Reference House increased its star rating by 0.1 stars only, but it improved the thermal performance of a 6.8 star house by 0.6 stars.

Downlights

The thermal performance benefit of removing downlights is significant. Once a house achieves a star rating of at least 5, then removing downlights generally provides around a 0.5 star improvement (depending on other thermal performance improvements). For designs, which achieve a star rating of between 7 and 8, removing downlights can provide the same level of thermal performance improvement as increasing wall and ceiling insulation from R6 to R10, and R8 to R10, respectively, in addition to changing double-glazed aluminum windows to thermally broken double-glazed windows. This shows that addressing 'weak' points in an otherwise well insulated building envelope can be far more cost effective than continuing to increase insulation levels. [22]

Since removing downlights significantly increases the thermal performance of houses for no cost, it means that the percentage increase in construction cost to achieve incremental improvements in thermal performance (by one star) can be much lower than the average percentage increases reported in the Chapter 5.

[22] A method to cover downlights to prevent infiltration losses/gains around them, which also permits roof insulation to be laid over the top without a fire risk, is currently being investigated by lighting manufacturers. This would enable recessed downlights to be installed without comprising a house's thermal performance.

Thermal mass

For the same designs, slab-on ground houses perform better thermally than timber floor houses in a cool-temperate climate.

Optimising the thermal mass of the slab-on-ground houses by tiling instead of carpeting as well as increasing slab thickness led to marginal increases in thermal performance. Adding or increasing slab insulation was far more cost effective in improving a house's thermal performance, as were other measures. Once the slab is insulated, optimizing thermal mass makes very little difference to a design's thermal performance. Although as previously described, optimal house shape and orientation improved a slab-on-ground house's thermal performance, irrespective of whether the thermal mass was being utilised. Although the results are relevant to a cool temperate climate, a cost analysis of a low energy home in Sydney (Bambrook et al 2011) also showed that other methods were more cost effective in improving thermal performance than optimizing thermal mass.

6.1.2 Correlation between cost and thermal performance

While it is generally the case, the results showed that it did not necessarily follow that spending more on a thermal performance measure will result in a higher level of thermal performance. The correlation between cost and star rating varies for each of the star bands. In the 5-6 star band, the correlation between cost and star rating is weak for both floor types for each house. This is because the costs to achieve 5-6 stars vary greatly depending on the method used. Compared to the 4-star Reference Houses, a rating of between 5 and 6 stars can be achieved for less cost or very little additional cost, while at the same time there also are very expensive methods that can be adopted.

The correlation between cost and star rating strengthens in the 6-7 star band range for both floor types (particularly the timber-floor) for each house. This reflects the fact that compared to the 5-6 star band range, there are few very low, or no cost opportunities to achieve this level of thermal performance; almost without exception financial investment is required to improve thermal performance. The exception is the Hickman slab-on-ground house where the correlation remains weak because on average less expenditure (per m^2 of floor area) needs to be spent to achieve this level of thermal performance.

In the 7-8 star band range, for the Kingston and Crimson houses, the correlation weakens for both for floor types. This is because very high cost designs do not necessarily provide a much better level of thermal performance than designs that are far less expensive.

6.1.3 The influence of house design on thermal performance

The results revealed that in general where one measure is more effective than another in improving thermal performance, that will be the case for each house. However, the level of improvement it achieves for each house can vary.

The star ratings houses achieve from a given thermal performance measure are useful for comparing current (and possible future) compliance costs of different house designs. However, as described in Chapter 3, a house's star rating is based on its adjusted space-conditioning energy requirement, not its actual (unadjusted) calculated energy requirement. The actual calculated space-conditioning energy requirement of houses needs to be compared in order to assess the influence of house design on thermal performance. The distinction between the adjusted and unadjusted space-conditioning energy requirements is important in the context of this study and is discussed below.

Each Reference House has a floor area of less than $200m^2$, which means their calculated space-conditioning load is adjusted down. Based on the conditioned floor area of each house, the energy reduction adjustments for the Kingston, Hickman and Crimson houses are approximately 25 %, 18 % and 16 % respectively. The houses' star ratings are based on these adjusted figures.

Generally, a larger house will have a smaller wall/floor ratio than a smaller house, which was the case for the Reference Houses. Table 6.2 below shows each house's floor area and wall/floor ratio. [23]

Table 6.2- Wall/floor ratio and floor area of houses

HOUSE	Wall/floor ratio	Floor area
Kingston	1	110 m^2
Crimson	0.9	177 m^2
Hickman	0.94	127m^2

For the timber floor houses that achieve a rating of between 5 and 6, or between 6 and 7 stars, a given design modification generally provides a lower star rating for the Crimson house than it does for the Kingston and Hickman houses, the star ratings of which are very similar. Figures 6.10 and 6.12 below show the unadjusted space-conditioning load ($MJ/m^2.a$) for the 5-6 and 6-7 star timber-floor houses that result from a given thermal performance improvement and Figures 6.11 and 6.13 show the corresponding star rating of the same thermal performance improvement for each house.

[23] (Note: the Kingston and Crimson houses have attached garages, which are included in the wall/floor ratios. However, even if garage walls are excluded, the Kingston and Crimson houses would still have the largest and smallest wall/floor ratios respectively.)

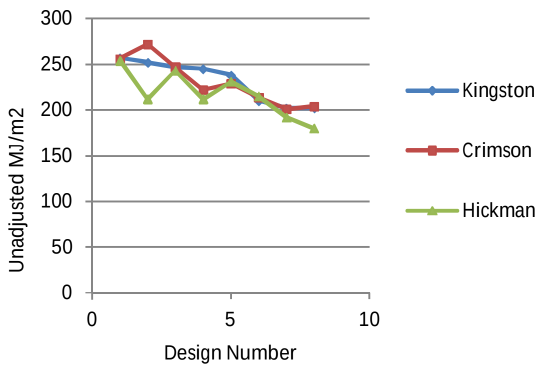


Figure 6.10- Unadjusted load (5-6 star timber floor)

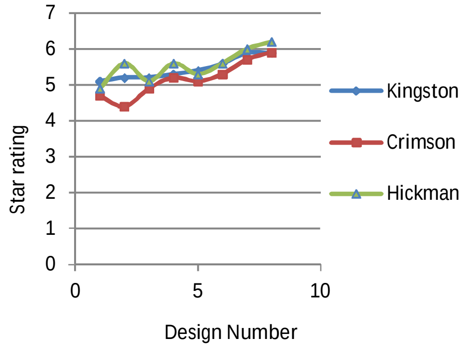


Figure 6.11- Star rating (5-6 star timber floor)

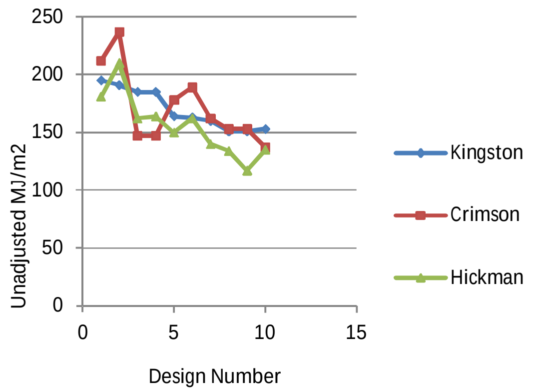


Figure 6.12- Unadjusted load (6-7 star timber floor)

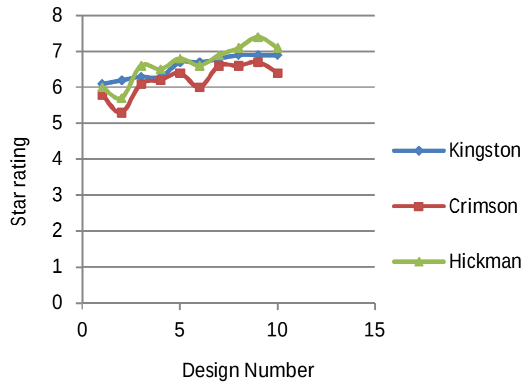


Figure 6.13- Star rating (6-7 star timber floor)

By comparing the two plots it can be seen that while the Crimson house achieves a lower star rating for all designs, there are designs for which the actual energy load ($MJ/m^2.a$) is the same or lower than the Kingston house; that is, it performs better thermally. This illustrates that where a thermal performance improvement results in the same, or even a higher space-conditioning load for two houses, the larger one (in this case the Crimson house) can attain a lower star rating because it is subject to a smaller percentage energy reduction.

However, this relationship between star rating and unadjusted energy load requirement for houses of different sizes does not always apply. The larger Hickman house has lower unadjusted energy requirement than the Kingston house for most designs, but despite the smaller percentage energy reduction, those designs attain similar, and even higher star ratings than the Kingston house. In this case, the Hickman house's better thermal performance cannot only be attributed to it being larger than the Kingston house; design is also a contributing factor. The Hickman house performs better thermally; that is, it has a lower unadjusted energy load for 5-6 and 6-7 star band ranges than the other two houses.

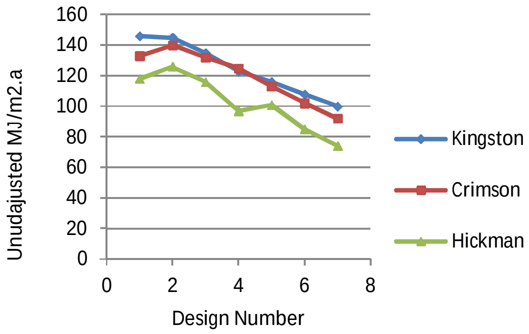


Figure 6.14 – Unadjusted load (7-8 star timber floor)

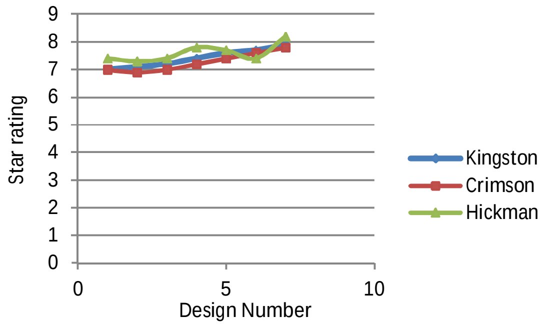


Figure 6.15 – Star rating (7-8 star timber floor)

Figure 6.14 and 6.15 above show the star rating and unadjusted space-conditioning energy load for timber-floor houses in the 7-8 star band range. A given thermal performance improvement provides a very similar star rating to each house.[24] Unlike the lower star band ranges, the unadjusted energy loads for the Crimson and Kingston house are very similar. While the two houses differ in size, their shape and room orientation are similar. In the 5-6 and 6-7 star band ranges, differences in the unadjusted energy load requirement between the two houses can reasonably be attributed to their different wall/floor ratios.[25]

The similarity of the unadjusted energy loads in the 7-8 star band range indicates that differences in wall/floor ratio may be less influential on space-conditioning load at high levels of thermal performance than at lower levels of thermal performance, at least for

[24] The star ratings for the Crimson house are marginally lower than for Kingston house, which in turn are marginally lower, except for one design, than the Hickman house

[25] The smaller Kingston house has a greater wall surface area compared to its floor area than the Crimson house. Therefore per m^2 of floor area it loses more heat through its external walls

houses whose floor plans and room layouts are similar. The difference in heat loss through each house's envelope becomes less significant as the overall R-value of the envelope is increased.

In contrast to the timber floor houses, for the slab-on-ground houses in the 5-6 and 6-7 star band range, each design modification for the Kingston house and Crimson house achieves very similar star ratings (see Figures 6.17 and 6.19 below). However, the Crimson house has a lower unadjusted space-conditioning energy load than the Kingston house (see Figure 6.16 below). For each design modification, the Hickman house achieves higher star ratings (and has lower unadjusted energy loads) than the two other houses (more so than for timber floor houses).

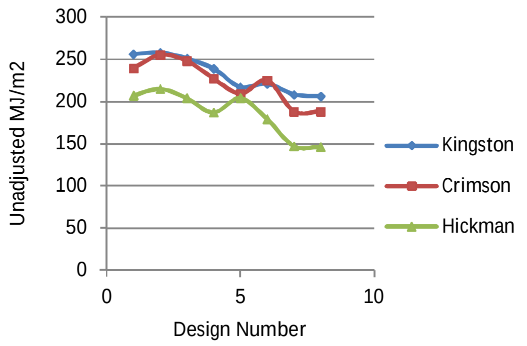


Figure 6.16 – Unadjusted load (5-6 star slab-on-ground)

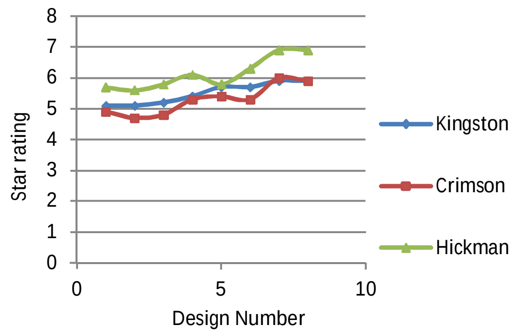


Figure 6.17 – Star rating (5-6 star slab-on-ground)

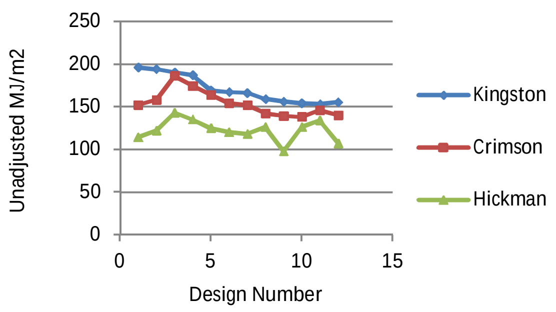


Figure 6.18 – Unadjusted load (6-7 star slab-on-ground)

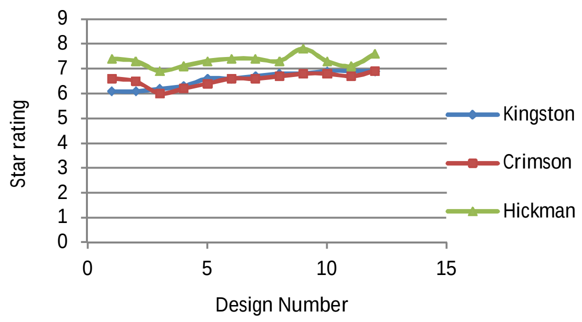


Figure 6.19 – Star rating (6-7 star slab-on-ground)

For the slab-on-ground houses in the 7-8 star band range, the Kingston and Crimson houses achieve very similar star ratings for each design modification, as was the case for the 7-8 star timber floor houses. The Hickman house performs best both in terms of star rating and unadjusted energy load requirement (see Figures 6.20 and 6.21 below).

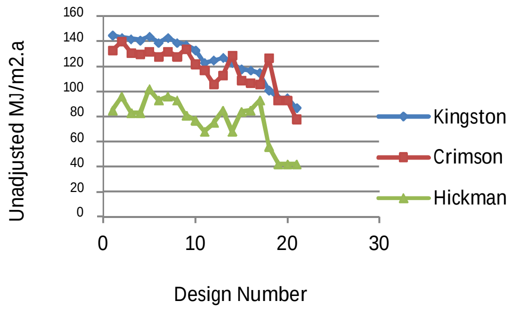


Figure 6.20 – unadjusted load (7-8 star slab-on-ground)

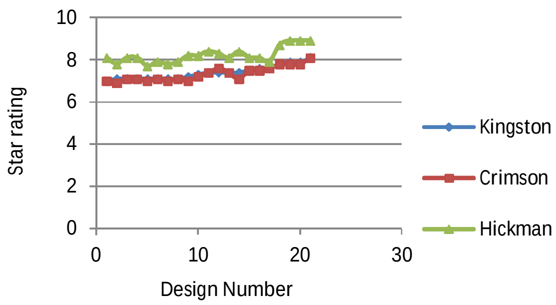


Figure 6.21 – Star rating (7-8 star slab-on-ground)

In summary, the star rating gained for each of the houses does not necessarily provide an indication of the houses' actual thermal performances relative to each other. For that a comparison of unadjusted loads is needed, which shows resulting thermal performance can be quite different despite star ratings being the same. It also shows that a large house will perform better than a smaller one, at least in the lower star band ranges, if their shapes and the layout of the rooms are similar. However, a smaller house can perform better thermally than a larger one (both in terms of star rating and energy usage) if it has a comparatively simple shape and its room layout is designed well. By virtue of its design, the Hickman house performs better thermally than the other two houses, for both floor types but particularly for the slab-on-ground version. In terms of maximizing thermal performance, this suggests slab-on-ground houses are more sensitive to shape and layout of the conditioned zones than timber floor houses. For the houses in this study this is true irrespective of whether the slab is carpeted or tiled. While for many designs the simulated winter temperatures of the living/dining rooms are very similar for each house, resulting in similar space-conditioning energy requirements, the simulated winter temperatures of the Hickman house's bedrooms are significantly higher than they are for the other two houses.

As an example Figure 6.23 below shows the simulated temperatures of Bedroom 2 in each house for a winter's week. It can be seen that the temperatures for Bedroom 2 of the Hickman house (shown in the light green) are higher than for the other two houses. Consequently, the Hickman house's better thermal performance can be attributed largely to the location of its bedrooms which all have a northerly aspect, whereas the other two houses have south facing bedrooms.

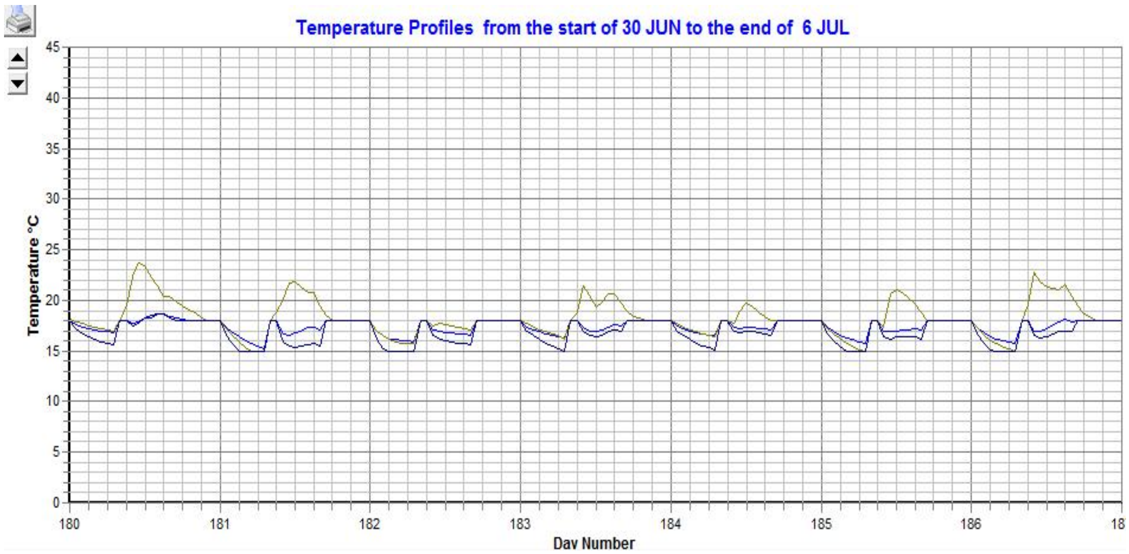


Figure 6.23- Simulated winter temperatures of Bedroom 2 in each house

6.1.4 Capital Costs

The implications of house design on the cost of achieving incrementally higher thermal performance levels are discussed below.

The results showed the average cost for each house to achieve a level of thermal performance within a particular star band range. However, these results need to be interpreted in context. The average cost includes very expensive designs that are unlikely to be adopted in practice. The reason they were included was so that their cost (and embodied energy) could be compared with alternative designs that achieve the same or similar level of thermal performance. Their inclusion also allowed the point of diminishing returns on insulation levels to be determined and to see how this changed when combined with other thermal performance modifications. Determining indicative average costs of achieving certain star ratings for houses in a cool temperate climate was not a primary goal of the study. [26]

All else being equal, timber floor houses achieve a lower star rating than slab-on-ground houses. This means that generally it is more expensive for a timber floor house to achieve a certain level of thermal performance than a slab-on-ground house. However, the results demonstrate that timber floor houses can achieve the same level of thermal performance as slab-on-ground for less cost. For this to occur a timber floor design requires thermal performance measures not adopted by the slab-on-ground designs. These include windows of a similar thermal performance which are much less expensive (double-glazed versus tripled glazed); more expensive windows but which provide a significant improvement in thermal performance (timber framed versus aluminium-framed); and no and very low cost modifications such as removing downlights and adding weatherstripping to windows.

The average cost ($\$/m^2$) for each house to achieve a rating of between 5 and 6 and 6 and 7 stars is a reflection of the relative level of thermal performance that designs provide to each one. For the Kingston and Crimson houses the average cost ($\$/m^2$) to achieve 7-8 stars is very similar for both floor types, as is the relative level of thermal performance that designs provide in those star band ranges. For the Crimson house, the average cost for both floor types in all star band ranges is slightly higher than it is for the Kingston house. This slight difference can be attributed to the difference in wall/floor ratio between the two houses. Kingston's higher wall/floor ratio results in increased wall insulation (as well as a greater percentage of better performing windows) per m^2 of floor than the Crimson house, hence its higher cost ($\$/m^2$).

For both floor types in the 5-6 and 6-7 star band ranges, Hickman has the lowest average cost ($\$/m^2$) to achieve 5-6 and 6-7 stars, despite not having the lowest wall/floor ratio. Its

[26] Although realistic indicative costs could reasonably be determined by removing super-insulated designs and perhaps other impractical solutions, such as increasing thermal mass, the costs of which were included in the calculation of averages costs. Furthermore, having all designs with weatherstripped windows and no downlights would have substantially reduced the average increase in costs to achieve each star band. It should also be noted that increase in cost is relative to the 4-star Reference houses, It is not the incremental cost of one star improvements.

lowest cost ($\$/m^2$) is due to the much better thermal performance that a given measure generally achieves for the Hickman house compared to the other houses, in particular for the slab-on-ground designs. There are other reasons, too. There were design modifications involving glazing area reductions which represented a larger reduction in glazing area for the Hickman house, and thus greater reduction in total building cost than it did for the other two houses.

Because of the Hickman bedrooms' optimal location as compared to the other houses, high star ratings can be achieved for slab-on-ground designs without the need to double-glaze bedroom windows. This has obvious implications for the cost of achieving high star ratings for each house.

If the orientation of a house results in its thermal performance being less than optimal, costs to increase its star rating are likely to vary from what the results in this study show. This would also have implications for embodied energy, and the cost effectiveness of measures in avoiding CO_2-e. Of course, a zero cost way of improving the thermal performance of a house in that case would be to orientate it optimally. Recent studies (Sustainability House 2012) which looked at redesigning 5 star houses to achieve 6 stars for the lowest possible cost showed that either mirroring the floor plan[27] or changing orientation could significantly improve thermal performance for no cost.

6.1.5 Cost effectiveness in saving CO_2-e

In this study cost effectiveness relates to the cost of a thermal performance improvement and the amount of CO_2-e avoided as a consequence of that improvement being implemented. In terms of current BCA compliance, and future compliance (although this may change to incorporate more than what it currently regulates) it is more relevant to relate the cost of thermal performance to CO_2-e avoided rather than energy saved.

[27] Mirroring the floor plan involves rotating the floor plan across the short axis of the house. So while the orientation of the house itself does not change, the orientation of conditioned rooms does.

While the cost of a design ($\$/m^2$) and the level of thermal performance that it provides can vary across the houses, in each star band range the same designs are generally amongst the most and least cost effective for all houses. However, the range in ranking between the houses of a design's cost effectiveness increases with each incremental increase in star band range.

In the 5-6 star band range, the ranking of designs for each house is very similar. The lowest cost designs were the most cost effective and involved reducing glazing areas. After reducing glazing areas, the next most cost effective change made to the Kingston and Hickman houses, irrespective of floor type, was to add R1.5 floor insulation. This change, however, is not as cost effective for the Crimson house because a slightly lower level of thermal performance is attained from the addition of floor insulation. Reducing glazing areas, double-glazing the windows of conditioned zones, or making minor increases in wall and ceiling insulation (R2.5 and R5.0 respectively) were the most cost effective for the slab houses. Double-glazing was more cost effective for the Crimson house whereas increasing the wall and ceiling insulation levels was more cost effective for the Hickman house. A smaller wall/floor ratio makes wall insulation more cost effective.

As for the 5-6 star band range, the least expensive designs are the most cost effective and the most expensive designs are the least cost effective. Common features to the most cost effective designs were reduced glazing area, double-glazing, and moderate levels of insulation, whereas the least cost effective designs had high levels of insulation.

The average range in ranking of designs in the 6-7 star band range was greater than it was for the 5-6 star band range. For most designs there is little difference between the rankings they provide for each of the houses. However, there are several designs for which the range in ranking is much higher than the average. For example, there were designs that were far more cost effective for the Hickman slab house than the other houses. Those designs had several things in common. First, they were slab-on-ground designs. Second, the windows of the living/dining room were reduced to 20% of the wall area and double-glazed, which represented a greater reduction in window area than for the other houses and therefore a greater reduction in cost. Third, combined with other changes, the level of thermal performance these designs provided for the Hickman house was much greater than for the other two houses, leading to a greater saving in CO_2-e.

On the other hand, there were designs that were far less cost effective for the Hickman house than the other two houses. These designs had two things in common. First, the windows areas in the bedrooms and living/dining rooms were reduced by about 30 % and double-glazed. While the percentage cost reduction that results from the reduced glazing area is about the same for each house, Hickman is still left with extensive areas of glazing in those rooms. The cost of double-glazing for the Hickman house results in greater percentage increase in total construction than it does for the other two houses. Second, combined with other changes, the level of thermal performance these designs provided for the Hickman house was only marginally greater than for the other two houses, indicating the CO_2 e savings across the houses are similar.

In the 7-8 star band range, the most cost effective designs were the least expensive. Common features to these designs are a slab-on-ground floor and timber-framed windows. For project homes built to current minimum thermal performance standards, aluminium windows are far more prevalent than timber windows, mainly because they are less expensive. However, if higher levels of thermal performance are introduced, the cost effectiveness of timber windows compared to alternative thermal performance measures may lead to their use becoming more widespread. This is also likely to lead to their cost falling.

The average range in rankings in the 7-8 star band range is greater than it was for the 6-7 star band range. Rather than this being the result of a greater difference in ranking for the houses for all designs, there are designs where the difference in ranking is significant. There are several designs that are far less cost effective for the Hickman house than the other two houses. However, unlike in the 6-7 star band range there is no combination of common factors that led to this being the case. In the 6-7 star band range design changes that involved reducing the glazing area by about 30 % and double-glazing were far less cost effective for the Hickman house. In the 7-8 star band range a design with the same design change is far more cost effective for the Hickman house than for the other two houses. This is because in combination with other changes, this design achieves a much higher level of thermal performance for the Hickman house than the other two. However, there is a design that is far less cost effective for the Hickman house than the other two that incorporates the same window change. In that case, the level of thermal performance is similar for the each house. In addition, the design incorporated very high insulation levels.

Depending on other design changes, the optimum insulation levels for the Hickman house are lower than for the other two houses because of its room layout. The thermal performance advantage of this has been discussed. This indicates that the point of diminishing returns for insulation levels is lower for the Hickman house than it is for the other two houses. This influences the comparative cost effectiveness for each house of certain design changes.

6.3 EMBODIED ENERGY AND COST

6.3.1 Correlations between embodied energy and cost

The correlation between cost and embodied energy is strong for both floor types for designs within the 5-6 and 6-7 star band ranges. Generally, this means that the more spent on achieving these star ratings, the greater the increase in a design's embodied energy. Interestingly, for the same designs the correlation between cost and thermal performance is much weaker. This leads to the situation where amongst the most expensive designs are ones that do not perform as well thermally as less expensive designs, but that have the highest embodied energy. However, there are low cost designs which achieve comparatively low levels of thermal performance, which have a low increase in embodied energy.

In the 5-6 and 6-7 star band ranges most design modifications involved reduced glazing areas, increased insulation levels and double-glazing, to varying degrees. Except for reduced glazing areas, these individual design modifications result in an increase in cost and embodied energy, which increase proportionally as more of a particular measure, such as insulation, is added. On the other hand, reducing the glazing areas leads to a reduction in construction cost. While the reduction in window area equals the net increase in external wall area, the external wall (with low to moderate levels of insulation) has a lower embodied energy/m^2 than that of a single glazed aluminium window (see Figure 6.24 below).

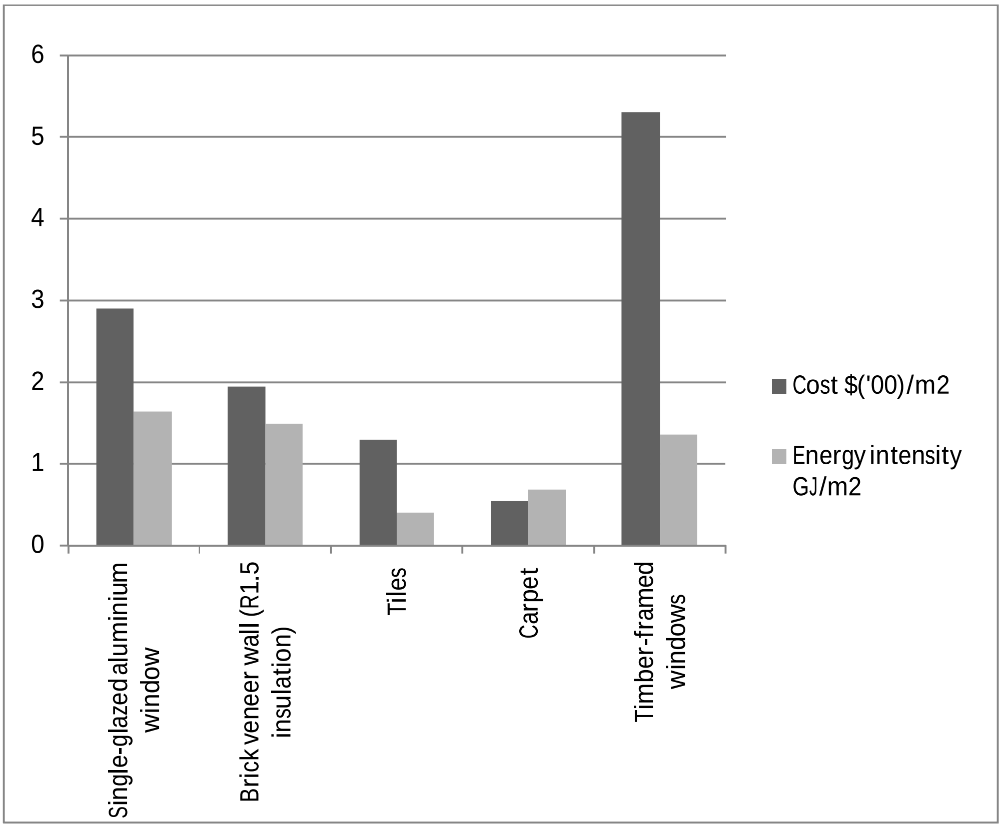


Figure 6.24 – Cost and energy intensity of building materials

For Kingston and Crimson house designs that achieve a rating between 7 and 8 stars, the correlation between cost and embodied energy is weak. The reason for this relates to the greater number of designs in this star band range with better performing windows and slab-on-ground designs that incorporate methods to utilize the slab's thermal mass. Timber framed windows have a lower embodied energy than aluminium framed windows, yet they are more expensive; considerably so if they are double- or triple-glazed. In addition tiles, which were used to utilize the slab's thermal mass, have a lower embodied energy than carpet but are more expensive (see Figure 6.24 above). It is this inverse cost/embodied relationship that results in the weak correlation between cost and embodied energy in the 7-8 star band range. [28]

For the Hickman house, the correlation between cost and embodied is weaker than it is for the lower star band ranges, although it is not as weak as it is for the Kingston and Crimson houses. This is because there are designs that only achieve a rating of between 6 and 7 stars for the Crimson and Kingston houses but achieve 7-8 stars for the Hickman house. As described above for designs in the 6-7 star band range the correlation between cost and embodied is reasonably strong.

6.3.2 The influence of house design and size on embodied energy

For designs in each star band range, for both floor types, it was clear which house performed best thermally. However, for those same designs, there was considerable variance between the houses as to which one had the highest or lowest increase in embodied energy in each star band range.

To a certain extent, the wall/floor ratio of a house affects the increase in embodied energy that results from improving its thermal performance. A reasonable expectation would be that a given thermal performance improvement would lead to the house with the largest wall/floor ratio having the greatest increase in embodied energy (per m^2 of floor area). However, the results showed that this was not always the case. For many of the designs, the Hickman house had the highest net increase in embodied energy (per m^2 of floor area).

In addition to wall/floor ratio there are several other factors that influenced the houses' relative increase in embodied energy. These included their original window sizes, areas of floor coverings (tiles and carpet), and for the Kingston and Crimson houses that they have attached garages with uninsulated floors for all levels of thermal performance. The

[28] It was previously mentioned that an outcome of the carbon tax will be that the carbon intensity of products will be reflected in their cost. This may not be the case where a less carbon intensive product is more a niche product than a more carbon intensive alternative e.g the case of aluminium and timber windows.

influence of each these factors on the houses' increase in embodied energy are discussed in turn.

There were three design modifications that included changes to window sizes. Each one involved reducing window areas to meet a certain window/wall ratio for reasons described previously. As the original window areas of the Reference Houses were different, each modification resulted in a different percentage reduction in window area for each house (see Table 6.3 below).

Table 6.3 - % reduction in window area

	W1	W2	W3
Kingston	50%	26%	33%
Crimson	38%	18%	21%
Hickman	48%	24%	25%

To a large extent the resulting increase in embodied energy (per m^2 floor area) of the window modifications is a function of each houses' original window areas. In the absence of any other design changes, each window modification resulted in the Kingston house having the greatest increase in embodied energy per m^2 of floor area. For two of those modifications the Hickman house had the lowest increase in embodied energy per m^2 of floor area, while the Crimson house had the lowest increase in embodied energy per m^2 of floor area for one of the modifications (see table above). The design change W1, for example, results in a greater reduction in glazing area for Hickman than for the other houses, and because glazing has a higher embodied energy than brick veneer wall (per m^2), it results in the Hickman house having a lower increase in embodied energy per m^2 of floor area. (This remains the case even where moderate to high insulation levels of wall insulation are used). However, a design change that results in the embodied energy of one house increasing more than another house does not necessarily result in it having the greatest increase in embodied energy per m^2. A house's wall/floor ratio also plays a role

The second factor affecting a house's increase in embodied energy is the area of carpet in the dining/living rooms and bedrooms as a proportion of floor area. Both modifications (T1 and T2) involving replacing carpet with tiles, result in a higher proportion of total floor area being tiled for the Hickman house than the other two houses (see Table 6.4 below). As a result, these modifications lead to a greater reduction in embodied energy/m^2 for the Hickman house than the other two houses.

Table 6.4 - Tiled area as % of total floor area

Design change	Kingston	Crimson	Hickman
T1	60 %	53%	73%
T2	40%	32%	45%

The two factors described above influenced which house had the highest (or lowest) increase in embodied energy. This partly explains the variability of the results. However, the main reason the average increase in embodied energy/m^2 is higher for the Hickman house is because unlike the other houses it does not have an attached garage. The attached garages of the Kingston and Crimson houses were not insulated under any of the different thermal performance scenarios because there was no benefit in doing so. The consequence of adding floor insulation to all three houses, excluding the garages, is a greater increase in embodied energy for the Hickman house per m^2 of floor area. This difference is exacerbated in the higher star band ranges where some of the designs incorporate moderate to high levels of floor insulation.

6.3.3 Increase in embodied energy and cost effectiveness in saving CO_2-e

As for the cost effectiveness of thermal performance modifications, in each star band range the most and least cost effective designs are in most cases common to all houses. Also, the range in the cost effectiveness ranking between the houses increases with each incremental increase in star band range indicating that a design that is cost effective for one house is not necessarily cost effective for another.

In the 5-6 star band range, the ranking in designs across the three houses is very similar. Predictably, designs with reduced window areas along with very modest increases in insulation levels are the most effective, whereas the least cost effective designs incorporated high levels of insulation. However, there are several designs for which there is a considerable difference in the ranking they provide for each house. For two of the designs, the Crimson house has a much lower ranking than the other two houses. Both designs involved reducing windows in the living/dining and bedrooms to 20% of the wall area. This modification results in a greater percentage reduction in both construction cost and embodied energy for the Kingston and Hickman houses than the Crimson house, making it appreciably more cost effective for them (see Figure 6.25 below).

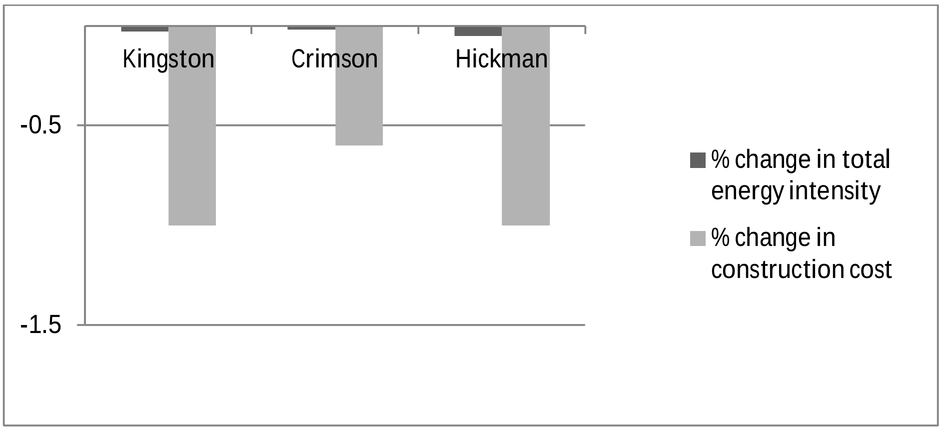


Figure 6.25 – Change in energy intensity and cost from reducing window areas in living/diningroom and bedrooms to 20% of wall area

However, a design that leads to one house having a greater increase in embodied energy than the other houses, does not necessarily mean it will be less cost effective for that house. Where a design for the Hickman house was less cost effective than for the other two houses, it was mainly attributable to a high level of floor insulation, which represented a greater percentage increase in construction cost for the Hickman house.

In the 6-7 and 7-8 star band ranges, the average range in rankings in cost effectiveness of designs across the houses is greater than it was for the 5-6 star houses. For most houses the ranking in cost effectiveness of designs is very similar, though there are several designs where the difference in ranking is considerable, explaining the higher average range in ranking. Several designs are considerably more cost effective for the Hickman house. For those designs, reducing the glazing area to the nominated window sizes represented a greater percentage area reduction for the Hickman house than the other two houses, which meant in turn, a greater cost saving leading to a higher cost effectiveness ratio.

6.4 NET CO_2 EMISSIONS AND COST

6.4.1 Cost effectiveness

Designs with the same level of thermal performance can have considerably different net increases in embodied energy. This was highlighted in the graphs in section 5.4 which showed that the correlation between embodied energy and thermal performance was not strong for either floor type in any of the star band ranges.

For houses that achieve a ranking of between 5 and 6 stars, a design's cost effectiveness ranking in saving space-conditioning emissions is similar overall to its ranking in saving net emissions. There is a greater difference between rankings in saving embodied emissions and net emissions. While there is some variation between the houses, their ranking in saving space-conditioning emissions is a reasonable indicator of ranking in saving net emissions.

For all houses in the higher star band ranges the difference between a design's cost effectiveness ranking for savings space conditioning emissions and saving embodied emissions, increased. This is explained by the methods used to achieve higher levels of thermal performance. For example, replacing carpet with ceramic tiles as a way of utilizing the slab's thermal mass was not cost effective in increasing thermal performance, though it is more cost effective in reducing embodied emissions because tiles have lower embodied energy than carpet. The same applies to triple-glazed windows.

Because of this difference in rankings between savings in space-conditioning emissions and savings in embodied emissions it follows that neither is necessarily a good indicator of a design's cost effectiveness in saving net emissions. However, generally the most and least cost effective designs in saving space-conditioning emissions are amongst the least and most cost effective in saving net emissions for all houses in all star band ranges.

6.4.2 What is the optimum level of thermal performance?

The results showed that in general the more money spent on a house's thermal performance improvement the greater the increase in its embodied energy (and emissions) and the greater the saving in its space-conditioning energy (and emissions). However, as the thermal performance of a house improves, the house's embodied emissions increase as a proportion of life cycle emissions. The question that then arises is "at what point does spending money on thermal performance improvements no longer become viable in terms of net savings of CO_2-e?" The answer to this depends on a number of factors. These include the level of thermal performance being sought, the cost of the thermal performance improvement, the emissions factor of the energy source, the design of the house and the climate in which the house is located. As the sensitivity analysis on the affect of different heating appliances on net emissions showed, the type and efficiency of the appliance is also a factor.

The houses of this study are located in Tasmania where the majority of the electricity is hydro-generated. The emissions factor for electricity generated in Tasmania is therefore significantly lower than it is for mainland states and territories. This emissions factor was applied to the space-conditioning energy savings that resulted from thermal performance improvements. On the other hand, the emissions factor that was used for calculating embodied emissions is significantly higher than for electricity generated in Tasmania. This disparity between the emissions factors used for space-conditioning energy and embodied energy had a significant bearing on the results.

The results showed that over a 25-year life the embodied emissions of a thermal performance improvement could outstrip the savings in space-conditioning emissions. At what level of thermal performance this occurs, and at what cost, depends on the design and size of the house. The Hickman house version that performed much better thermally than the other two houses for most design changes was able to achieve higher levels of thermal performance before embodied emissions began to outstrip the savings in space-conditioning emissions. For the two other houses, a rating of between 5 and 6 stars was the maximum level of thermal performance they could achieve while still meeting the energy efficiency objective of the BCA. However, as shown in the sensitivity analysis, the same house designs built in the same climate in Victoria would meet the objective because the emissions intensity of electricity is much higher there.

Figures 6.26, 6.27 and 6.28 show the total embodied and space-conditioning emissions for particular 5, 6 and 7 star designs of the study houses.[29] Clearly, as thermal performance increases, total embodied emission increase while space-conditioning emissions decrease. It can also be seen that the larger the house, the greater the total net emissions (the sum of embodied and space-conditioning emissions).

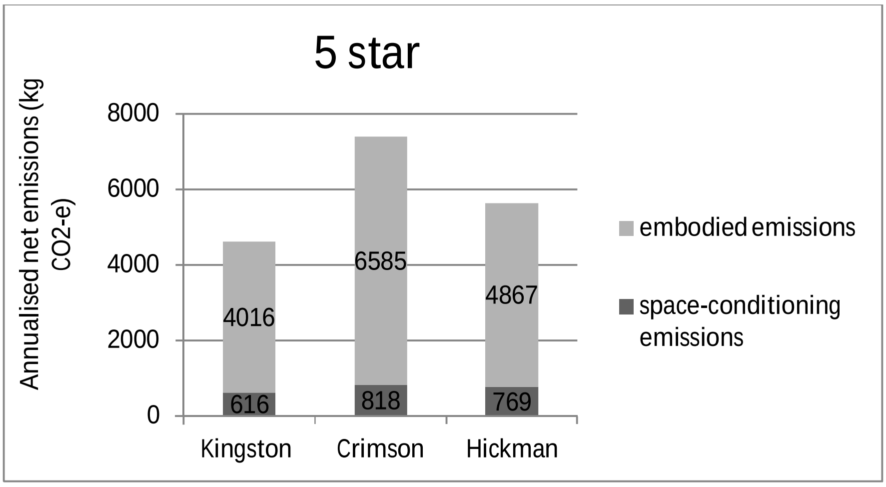


Figure 6.26 - Annualised net emissions of 5 star houses

[29] This is an example for particular designs that achieve those star ratings. As described in the results there are numerous thermal performance modifications that achieve a certain star rating, but which have different embodied emissions. Therefore, the relative contributions of embodied and space-conditioning emissions can vary for the same Reference House with same star rating.

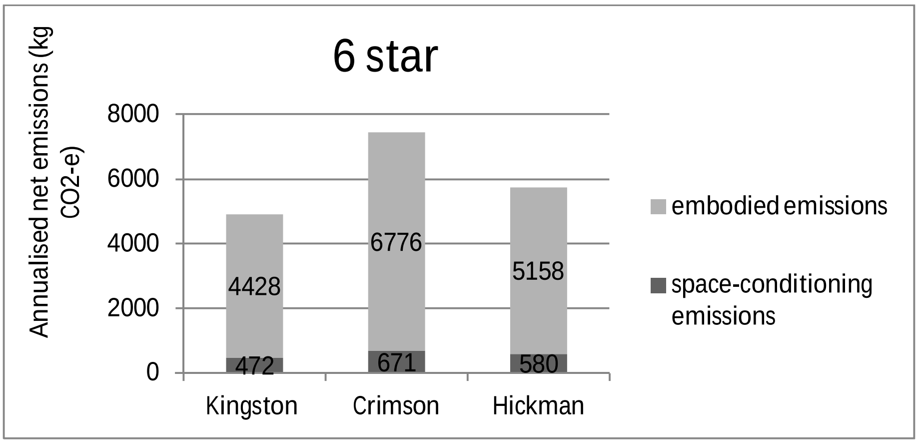


Figure 6.27 – Annualised net emissions of 6 star houses

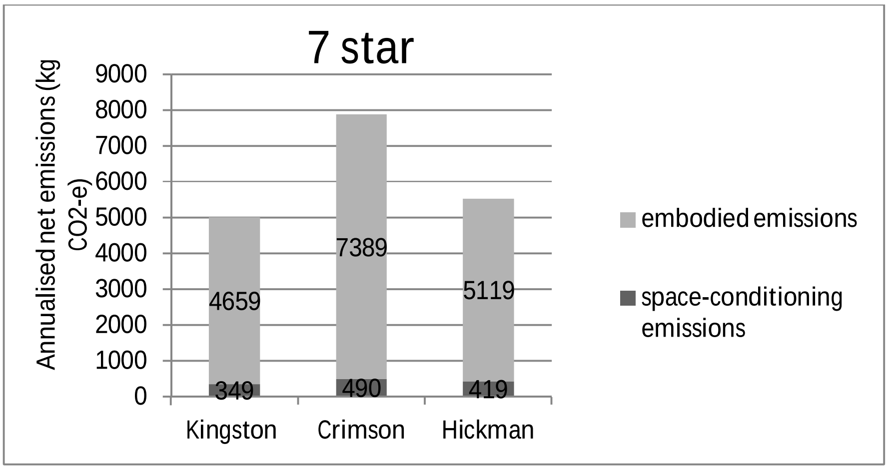


Figure 6.28 – Annualised net emissions of 7 star houses

Figure 6.29 below shows that while the annual space-conditioning emissions are lower for the 7 star house (Crimson) than the 5-star houses, its annualized net emissions are higher. Future energy efficiency regulations for housing are unlikely to extend beyond operational energy (or emissions) to include embodied energy (or emissions). However, it is evident that embodied emissions are significant, to the degree that larger houses by virtue of their higher embodied energy can have higher annualized net emissions than smaller houses which have considerably lower levels of thermal performance.

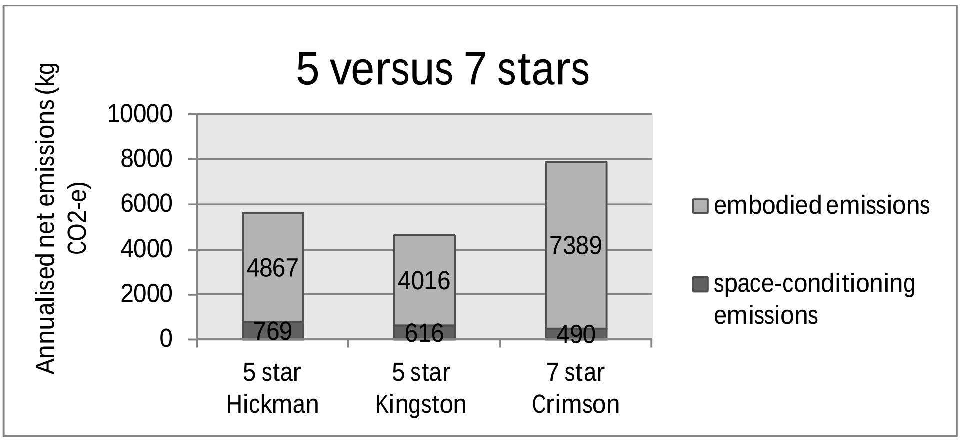


Figure 6.29 – A comparison of the annualised net emissions of houses with different star ratings

As discussed in Chapter 3 an argument made against increasing thermal performance standards is that it would lead to houses becoming less affordable. However, similar arguments were not made about the effects of the trend to larger houses on affordability. The Crimson house is approximately $89,000 (or 60%) more expensive than the Kingston house. That additional cost far exceeds the most expensive thermal performance improvement made for the Kingston house to achieve a star rating of between 7 and 8 stars.

6.4.3 Cost effectiveness to the home-owner

This study has examined the cost-effectiveness of thermal performance improvements in saving (or avoiding) CO_2 emissions. A study finding was that increasing the thermal performance of the Reference Houses (each with approximately a 4-star rating) to above 5 stars resulted in an increase in net CO_2 emissions for the majority of designs. This outcome runs counter to the energy efficiency provisions of the BCA, which is to minimise greenhouse gas emissions. The amount of CO_2 savings aside, higher standards have only been introduced if a Regulatory Impact Study has found that they will be cost effective to the home-owner, that is, the accrued savings from reducing space-conditioning energy use over a house's life will be greater than the resultant increase in construction cost.

A cost benefit analysis was undertaken to determine the levels of thermal performance that can be achieved and which are cost effective to the home-owner.[30] Retail electricity and gas price forecasts (accounting for a low and high carbon price) were adopted from the report *Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards* (2012). A 7% discount rate was used and the benefit-cost analysis was over 25 years to align with the modelling period used to calculate the main results.

Table 6.5 below shows that for each house, 7 stars is very cost-effective to the home-owner when electric heating (with 100% efficiency) is used. The Hickman house is the most cost-effective, with benefits exceeding costs by at least a benefit-cost ratio of 2. These results indicate that while increasing thermal performance to 6 and 7 stars may not be warranted in terms of avoiding CO_2-emissions, it is financially worthwhile to the home-owner.[31]

Table 6.5 – Benefit-cost ratios of achieving a 6 and 7 star rating (electric heating 100% efficient)

	Kingston	Crimson	Hickman
6 star (low carbon price)	2.2	2.0	2.7
6 star (high carbon price)	2.4	2.2	2.9
7 star (low carbon price)	1.2	0.9	2
7 star (high carbon price)	1.3	1.0	2.2

Table 6.6 and 6.7 below show the benefit-cost ratios when different heating appliances are used. Table 6.6 shows that when electric heating (heat pump having an efficiency of 350%) is used in the Reference Houses, improving the thermal performance to 6 or 7 stars is not cost effective for any of the houses, under either of the carbon pricing scenarios. Compared to when less efficient electric heating is used, a given thermal performance improvement results in lower energy savings because of the heater's higher efficiency.

[30] The results are based on the lowest cost designs that achieve a 6 and 7 star rating for each house.
[31] Simple payback is around 7-8 years

Table 6.6 – Benefit-cost ratios of achieving a 6 and 7 star rating (electric heating 350% efficient)

	Kingston	Crimson	Hickman
6 star (low carbon price)	0.61	0.58	0.76
6 star (high carbon price)	0.64	0.6	0.84
7 star (low carbon price)	0.33	0.24	0.57
7 star (high carbon price)	0.37	0.28	0.62

Table 6.7 shows that when gas heating is used in the Reference Houses, improving the thermal performance to 6 stars is cost effective for each house under both carbon pricing scenarios. However, of the 7 star houses, only the Hickman house is cost effective because it can achieve 7 stars at a lower cost ($\$/m^2$) than the Kingston and Crimson houses.

Table 6.7- Benefit-cost ratios of achieving a 6 and 7 star rating (gas heating efficient)

	Kingston	Crimson	Hickman
6 star (low carbon price)	1.2	1.1	1.4
6 star (high carbon price)	1.3	1.2	1.6
7 star (low carbon price)	0.64	0.48	1.1
7 star (high carbon price)	0.69	0.52	1.2

6.5 CONCLUSION

This Chapter discussed how the choice of materials and methods used to improve the thermal efficiency of houses affects capital cost. It was shown that while there are diminishing returns on certain materials and methods, such as incrementally increasing insulation levels, others such as removing downlights and improving the R-value of window frames, can become more cost effective as thermal performance improves.

The relationship between cost and embodied energy was discussed and the material and design choices which weaken the correlation between them explained. The differences in design that affected the houses' increase in embodied energy as result of a given thermal performance improvement were also analysed, the primary ones being the original window area of houses and tiled floor area.

In terms of cost effectiveness of thermal performance improvements in avoiding space-conditioning emissions, embodied emissions and net emissions, generally the least and most cost effective designs are common to each house. However, this is not always the case and reasons for this were discussed.

How house size and design affects net emissions was discussed, with it being evident that the additional embodied emissions associated with a larger house can outstrip any savings in emissions that result from improving thermal performance. Finally, the cost effectiveness of thermal performance to the home-owner was examined. The level of thermal performance that is cost effective depends on the type of heating appliance used as well as on house design.

CHAPTER 7 - CONCLUSION

The aim of this research was to determine and rank the cost effectiveness of minimizing CO_2-e by utilising a wide range of methods to improve houses' thermal performance, which was successfully undertaken. The research aim arose from the problem identified in the literature review; that is, when considering increasing thermal performance regulations, the associated increase in embodied emissions and the influence they have on the cost effectiveness of higher star ratings are not taken into account. In order to address the aim it was necessary to understand the theory and practice of incrementally improving the thermal performance of houses. In addressing the aim, the three primary research questions were answered and hypothesis that ***The cost effectiveness of reducing CO_2-e through improved thermal performance varies significantly depending on the materials and methods used*** has clearly been upheld.

Numerous methods can be used to improve the thermal performance of a house to pre-determined levels, with costs varying significantly. The lowest cost improvements typically involve a combination of several methods. However, it is also clear that certain individual methods are far more cost effective than others in improving thermal performance. These include reducing window sizes, using moderate levels of insulation to all parts of the building envelope, and addressing 'holes' in the building envelope by weatherstripping windows and by using alternative ceiling mounted lighting to replace downlights.

Nonetheless, some methods that are not cost effective for achieving lower star ratings become cost effective when increasingly higher levels of thermal performance are being sought. Timber windows are the primary example. To achieve the lower star ratings, there are less expensive options than changing from aluminium to timber frame windows. However, when striving for higher levels of thermal performance the less expensive options have already been deployed. Changing to timber windows is cost effective compared to many other options partly because the resulting increase in cost is not substantial, but mainly due to the significant thermal performance improvement they provide. The most cost effective designs in the 7-8 star band range were slab-on ground houses with timber windows.

The least cost effective methods in improving thermal performance include high levels of insulation to one or more parts of the building envelope, triple-glazed windows, and in the case of slab-on-ground designs, methods to optimize thermal mass.

In terms of cost effectiveness in avoiding space-conditioning CO_2-e emissions, generally the most and least cost effective designs are the same for each house. The cost effectiveness of one design in relation to the other two, whether far less or far more effective, is attributable to differences in glazing areas or a design providing a much better improvement in thermal performance for one house over the other two.

The designs with the lowest and highest embodied energy in the 5-6 and 6-7 star band ranges are generally the least and most expensive designs, respectively. And generally, the high embodied energy/high cost designs do not necessarily result in the greatest level of thermal performance of all designs in particular star band range. Designs with the highest embodied energy typically had high levels of insulation which is expensive, relatively high in embodied energy, and does not necessarily provide the level of thermal performance of less expensive alternatives.

In the 5-6 and 6-7 star band ranges, generally the most and least cost effective designs in minimizing embodied emissions are the same for each house. However, in the 7-8 star band range the ranking of designs across the three is less uniform. For some thermal performance improvements used to attain a 7-8 star rating, design differences between the houses are a significant factor in determining how cost effective the improvement will be in minimizing embodied emissions. These include floor/wall ratio, the area of floor tiling and window areas.

In the 5-6 star band range in terms of saving net emissions, designs that are the most cost effective are the ones that are also the most cost effective in saving space-conditioning emissions. They are low cost designs, where the resulting increase in embodied emissions is also relatively low. However, in the higher star band ranges cost effectiveness in saving space-conditioning emissions cannot be used to predict reliably the cost effectiveness in saving net emissions. Designs that are more cost effective in avoiding embodied emissions can be the ones that are more cost effective in saving net emissions. This is because the relationship between cost and embodied energy becomes weaker, particularly in the 7-8 star band range as a result of a greater proportion of designs having floor tiles (in the case of slab-on-ground designs) and timber windows.

While the cost-effective rankings of numerous thermal performance improvements were established, on their own they do not provide an indication of whether a design actually leads to a net savings in emissions. A design may be equally cost effective for all houses, but the house design and size determines whether it leads to a net saving in emissions as compared to 4 star Reference Houses. The net emissions of the Crimson and Kingston houses increased as their star rating increased from 5 to 7 stars because the increase in embodied emissions of the thermal performance improvements outweighed the decrease in space-conditioning emissions. On the other hand, for the Hickman house there is a slight decrease in net emissions from 5 to 7 stars because generally the Hickman house achieves a higher star rating for a given thermal performance improvement. In addition, higher star ratings could be achieved using lower embodied energy designs. A 5 star Hickman house can be responsible for fewer net emissions than a 7 star Crimson house. This is because it is smaller, and therefore there are fewer embodied emissions associated with given thermal performance improvements, and because its design lends itself to better thermal performance.

Determining the level of thermal performance (star rating) that is cost effective to the householder was not a primary goal of this study. However, it was calculated to determine its relationship with net savings in emissions. As for net savings in emissions, cost effectiveness to the householder of thermal performance depends on the level of thermal performance being sought as well as the type and efficiency of space-conditioning appliances used. It is only when gas heating is used that improving the thermal performance to achieve between a 6 and 7 star rating reduces net emissions and is also cost effective to the home-owner, for all of the houses.

Further research

This research involved houses in a cool-temperate climate where space-conditioning energy is dominated by heating. Repeating this research in other climate zones where the heating and cooling requirements for houses are different and, as a result different materials and methods for improving thermal performance are required, would be worthwhile.

In the future the costs of some of the materials used to improve thermal performance in this research are likely to fall as their uptake increases. It would be interesting to determine the relative cost effectiveness of the various designs described as a result of falling costs for some materials.

This research assumes that theoretical space-conditioning energy requirements match actual space-conditioning requirements. It is recognized that this is unlikely in the case of all houses. Further research and monitoring of actual space-conditioning energy use of houses in a cool-temperate climate would also be also worthwhile.

A major conclusion from this research is that embodied emissions are very significant. However, despite the objective of the energy efficiency provisions of the BCA being to reduce greenhouse gas emissions, only the emissions associated with the operational energy of houses are regulated. Further research into what are the optimum levels of thermal performance in terms of reducing life-cycle greenhouse emissions for other capital city climate zones would also be worthwhile.

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APPENDIX A – COST OF THERMAL PERFORMANCE IMPROVEMENTS

Kingston: cost of design changes to achieve a rating of 5-6 stars

Design 1 (W1, W4)	Unit	Rate	Sub-total
Reduce windows in living/diningrom and bedrooms to 20% of wall area	-13.32	$290	-$3,862.80
Double glaze new glazing area	12.07	$230	$2,776.10
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation,	13.32	$195	$2,597.40
		TOTAL	**$1,510.70**
Design 2 (W1, R6)			
Reduce windows in living/diningrom and bedrooms to 20% of wall area	-13.32	$290	-$3,862.80
$195/m2).	13.32	$195.00	$2,597.40
R2.5 wall insulation	83	$5.10	$423.30
		TOTAL	**-$842.10**
Design 3 (L1, R8, R6)			
R2.5 wall insulation	83	$5.10	$423.30
R1.5 floor insulation	86	$12.80	$1,100.80
		TOTAL	**$1,524.10**
Design 4 (R8, W1)			
Reduce windows in living/diningrom and	-13.32	$290	-$3,862.80
Extra bwk/ins/sis/plas/paint 13.32 x	13.32	$195.00	$2,597.40
R1.5 floor insulation	86	$12.80	$1,100.80
		TOTAL	**-$164.60**
Design 5 (R12, R6, L1)			
R2.5 wall insulation	83	$5.10	$423.30
R2.5 floor insulation	86	$17.80	$1,530.80
		TOTAL	**$1,954.10**
Design 6 (W1,R7)			
Reduce windows in living/diningrom and	-13.32	$290	-$3,862.80
Extra bwk/ins/sis/plas/paint 13.32 x	13.32	$195.00	$2,597.40
R2.5 wall insulation	83	$5.10	$423.30
R5.0 ceiling insulation	110	$3.63	$399.30
			-$442.80
Design 7 (R1)			
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	83	$5.10	$423.30
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,698.00	$1,698.00
			$3,165.60
Design 8 (R2)			
R6 floor insulation (labour)	86	$9	$774.00
R6 floor insulation (materials)	1	$3,348	$3,348.00
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	83	$26	$2,158.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	97	$12.60	$1,222.20
Extra brickwork			$94.00
		TOTAL	**$11,094.04**

Design 9 (W2) (R9)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
R6 wall insulation				$5,655.84
Extra insulation over base.			$43.30	$43.30
R8 ceiling insulation				$1,316.20
			TOTAL	**$6,361.74**
Design 10 (R4)				
R10 floor insulation				
Labour		172	$4.50	$774.00
Materials 2x R4.0 EPS + 1 X R2.0 EPS=29 sheets X$64 + 29 sheets X$43		1	$4,959	$4,959.00
R10 wall insulation				$6,305
R12 ceiling insulation		110	$27.55	$3,030.50
Extra 360mm brickwork		6.84	$65	$444.60
			TOTAL	**$15,513.10**
Design 11 (W1, C1)				
Reduce windows in living/diningrom and bedrooms to 20% of wall area		-13.32	$290	-$3,862.80
Extra bwk/ins/sis/plas/paint 13.32 x		13.32	$195.00	$2,597.40
R2.5 wall insulation		83	$5.10	$423.30
R5.0 ceiling insulation		110	$3.63	$399.30
R1.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
			TOTAL	**$640.70**
Design 12 (W2, W3, R7)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/diningroom		15.04	$230	$3,459.20
R2.5 wall insulation		90	$5.10	$459.00
R5.0 ceiling insulation		110	$3.63	$399.30
			TOTAL	**$3,663.90**
Design 13 (W2, C2)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
R1.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
R6 wall insulation				$5,655.84
Extra insulation over base.			$43.30	$43.30
R8 ceiling insulation				$1,316.20
			TOTAL	**$7,445.24**
Design 14 (R12, R6, L1, W5)				
Timber window frames		27.38	$70.00	$1,916.60
R2.5 wall insulation		83	$5.10	$423.30
R2.5 floor insulation		86	$17.80	$1,530.80
			TOTAL	**$3,870.70**

Design 15 (W2, W5, R9)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Timber window frames (difference bwteen aluminium and timber frames)		20.5	$70.00	$1,435.00
R6 wall insulation				$5,655.84
Extra insulation over base.			$43.30	$43.30
R8 ceiling insulation				$1,316.20
				$7,796.74
Design 16 (W2, R2)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
R6 floor insulation (labour)		86	$8	$645.00
R6 floor insulation (materials)		1	$3,700	$3,700.00
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		83	$26	$2,158.00
R2 polystyrene (labour and materials)		1	$1,436	$1,436.00
R8.0 ceiling insulation		97	$12.60	$1,222.20
			TOTAL	**$10,566.44**

Kingston: cost of design changes to achieve a rating of 6-7 stars

		Unit	Rate	Sub-total
Design 1 (W2, R1, W3)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze living/diningroom		15.04	$230	$3,459.20
R1 (as above)				$ 3,200.00
			TOTAL	**$6,005.60**
Design 2 (W9, W3, T1, C7)				
Reduce windows in liv/diningroom to 20% of wall area		-8.66	290	-$2,511.40
Extra bwk/ins/sis/plas/paint.		8.66	$195	$1,688.70
Double glaze liv/diningroom		9.19	$ 230	$2,113.70
Tiles in lieu of carpet		66.6	$74	$4,928.40
Extra 100mm slab		1	$ 2,000	$2,000.00
R3.0 slab insulation		1	2200	$2,200.00
R2.5 wall insulation		89	$5.10	$453.90
R5.0 ceiling insulation		110	$3.63	$399.30
			TOTAL	**$11,272.60**
Design 3 (W9, W3, C2)				
Reduce windows in liv/diningroom to 20% of wall area		-8.66	290	-$2,511.40
Extra bwk/ins/sis/plas/paint.		8.66	$195	$1,688.70
Double glaze liv/diningroom		9.19	$ 230	$2,113.70
R6 wall insulation				$5,655.84
Extra insulation over base.			$350.00	$350.00
R8 ceiling insulation				$1,316.20
R1.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
				$9,696.54
Design 4 (W2, R1, W4)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.5	$230	$4,255.00
R5.0 ceiling insulation		110	$3.63	$399.30
R2.5 wall insulation		89	$5.10	$453.90
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
			TOTAL	**$6,797.60**
Design 5 (W2, W3, C1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/diningroom		15.04	$230	$3,459.20
R2.5 wall insulation		89	$5.10	$453.90
R5.0 ceiling insulation		110	$3.63	$399.30
R1.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
			TOTAL	**$4,742.30**

Design 6 (W2, W4, C1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.5	$210	$3,885.00
R2.5 wall insulation	89	$5.10	$453.90
R5.0 ceiling insulation	110	$3.63	$399.30
R1.0 under slab			
Labour	1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)	31	$28.50	$883.50
		TOTAL	**$5,168.10**
Design 7 (W2, W4, R13)	Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R2.5 wall insulation	89	$5.10	$453.90
R5.0 ceiling insulation	110	$3.63	$399.30
R6 floor insulation (labour)	86	$9	$774.00
R6 floor insulation (materials)	1	$3,348	$3,348.00
		TOTAL	**$8,578.90**
Design 8 (W2, W4, R10)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.5	$230	$4,255.00
R5.0 ceiling insulation	110	$3.63	$399.30
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,698.00	$1,698.00
R4 wall insulation			$ 4,000.00
		TOTAL	**$10,343.70**
Design 9 (W2, W3, C2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/diningroom	15.04	$230	$3,459.20
R6 wall insulation			$5,655.84
R8 ceiling insulation			$1,316.20
R1.0 under slab	1	$200.00	$200.00
Labour	31	$28.50	$883.50
Materials (31 sheets of EPS @$28.50 each)			
		TOTAL	**$10,861.14**
Design 10 (W2, W4, C2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R6 wall insulation			$5,655.84
R8 ceiling insulation			$1,316.20
R1.0 under slab			
Labour	1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)	31	$28.50	$883.50
		TOTAL	**$11,659.24**

Design 11 (W2, W4, C2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R6 wall insulation			$5,250.00
R8 ceiling insulation			$1,316.20
R1.0 under slab			
Labour	1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)	31	$28.50	$883.50
		TOTAL	**$11,253.40**
Design 12 (W2, W3, R2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/diningroom	15.04	$230	$3,459.20
R6 floor insulation (labour)	86	$9	$774.00
R6 floor insulation (materials)	1	$3,348	$3,348.00
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	89	$26	$2,314.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
Extra brickwork			$720.00
		TOTAL	**$14,845.44**
Design 13 (W4, W1, R5)			
Reduce windows in living/diningrom and bedrooms to 20% of wall area	-13.32	$290	-$3,862.80
Double glaze new glazing area	12.07	$230	$2,776.10
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation,	13.32	$195	$2,597.40
R5.0 floor insulation			$ 5,100.00
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	96	$26	$2,496.00
R2 polystyrene (labour and materials)	1	$1,850	$1,850.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
			$14,401.54
Design 14 (W2, W4, R1, T1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	89	$5.10	$453.90
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,698.00	$1,698.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
			$11,728.30

Design 15 (W2, W4, C3, T1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
Tiles in lieu of carpet		66.6	$74	$4,928.40
R5.0 ceiling insulation		110	$3.63	$399.30
R2.5 wall insulation		89	$5.10	$453.90
R3.0 slab insulation		1	2200	$2,200.00
50mm extra slab				$1,000
			TOTAL	**$12,585.30**
Design 16 (W2, W4, R2)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R6 floor insulation (labour)		86	$9	$774.00
R6 floor insulation (materials)		1	$3,148	$3,148.00
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		89	$26	$2,314.00
R2 polystyrene (labour and materials)		1	$1,339	$1,339.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
				$15,343.54
Design 17 (W2, W4, C7, T1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.5	$230	$4,255.00
Tiles in lieu of carpet		66.6	$74	$4,928.40
Extra 100mm slab		1	$ 1,900	$1,900.00
R3.0 slab insulation		1	2000	$2,000.00
R2.5 wall insulation		89	$5.10	$453.90
R5.0 ceiling insulation		110	$3.63	$399.30
				$13,283.00
Design 18 (W2, W4, C7, T2)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
Extra 100mm slab		1	$ 2,000	$2,000.00
R3.0 slab insulation		1	2000	$2,000.00
R2.5 wall insulation		89	$5.10	$453.90
R5.0 ceiling insulation		110	$3.63	$399.30
Tiles in lieu of carpet		43.3	$74	$3,204.20
				$11,661.10

Design 19 (W2, W4, C4)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		89	$26	$2,314.00
R2 polystyrene (labour and materials)		1	$1,200	$1,200.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
R2.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
				$12,366.04
Design 20 (W2, W4, R3, W5)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
Timber window frames		20.5	$70.00	$1,435.00
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		90	$26	$2,340.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
				$15,325.54
Design 21 (W2, W4, R11)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R8 floor insulation				
Materials				$3,400.00
Labour				$ 774.00
R8 wall insulation				$ 5,628.00
R10 ceiling insulation				$ 1,400.00
				$14,805.70
Design 22 (W2, W4, R10)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$195	$3,609.45
R5.0 ceiling insulation		110	$3.63	$399.30
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
R4 wall insulation				4600
				$10,298.15

Kingston: cost of design changes to achieve a rating of 7-8 stars

Design 1 (W2, W8, R1)	Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze liv/din and bedrooms	18.55	$ 936	$17,362.80
Single timber glazing elsewhere	5	$ 120	$600.00
R5.0 ceiling insulation	110	$ 3.63	$399.30
R2.5 wall insulation	89	$ 5.10	$453.90
R3.0 floor insulation			
Materials			$ 1,674.00
Labour			$ 645.00
			$20,481.40
Design 2 (W2, W4, C4, T1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	89	$26	$2,314.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
Extra brickwork			$230.00
R2.0 under slab			
Labour	1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)	31	$28.50	$883.50
Tiles in lieu of carpet	66.6	$74	$4,928.40
			$17,043.44
Design 3 (W2, W4, C4, T2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	89	$26	$2,314.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
Extra brickwork			$720.00
R2.0 under slab			
Labour	1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)	31	$28.50	$883.50
Tiles in lieu of carpet	43.3	$74	$3,204.20
			$15,809.24

Design 4 (W2, W4, C4, T1 + extra 100mm slab)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		89	$26	$2,314.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
R2.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
Tiles in lieu of carpet		66.6	$74	$4,928.40
Doube slab thickness				$2,000
				$19,533.44
Design 5 (W2, W4, R4)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R10 floor insulation				
Labour		172	$4.50	$774.00
Materials 2x R4.0 EPS + 1 X R2.0 EPS=29 sheets X$64 + 29 sheets X$43		1	$4,959	$4,959.00
R10 wall insulation				$6,305
R12 ceiling insulation		110	$27.55	$3,030.50
Extra 360mm brickwork		6.84	$65	$444.60
				$19,116.80
Design 6 (W2, W4, C4, T1 + extra 50 mm slab)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$195	$3,609.45
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		89	$26	$2,314.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
R2.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		62	$28.50	$1,767.00
Tiles in lieu of carpet		66.6	$74	$4,928.40
Extra 50mm slab				$1,000
				$18,769.09

Design 7 (W2, W4, R3)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		90	$26	$2,340.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$2,600.00
				$ 14,792.54
Design 8 (W2, W4, C6)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
R10 wall insulation				$6,305
R12 ceiling insulation		110	$27.55	$3,030.50
200 mm slab				$2,000
				$17,282.20
Design 9 (W2, W4, C8)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R3.0 floor insulation (labour)		89	$7.50	$667.50
R3.0 floor insulation (materials)		1	$1,900.00	$1,900.00
R8 wall insulation				$ 5,628.00
R10 ceiling insulation				$ 1,950.00
200 mm slab				$2,000
				$15,749.20
Design 10 (W2, W4, C5)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R10 wall insulation				$6,205
R12 ceiling insulation		110	$27.55	$3,030.50
Extra 360mm brickwork		6.84	$65	$444.60
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
150mm slab				$1,000
				$16,626.80

Design 11 (W2, W8, R14)	Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1065	$19,702.50
Single timber glazing elsewhere	5	$ 120.00	$600.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	90	$5.10	$459.00
R6 floor insulation (labour)	86	$9	$774.00
R6 floor insulation (materials)	1	$3,348	$3,348.00
			$24,629.20
Design 12 (W2, W4, W7, T1, C3)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Argon filled double glazed windows	18.51	$ 252	$4,664.52
Tiles in lieu of carpet	66.6	$74	$4,928.40
R3.0 floor insulation			$2,200.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	90	$5.10	$459.00
			$11,997.62
Design 13 (W2, W4, R3, T1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Tiles in lieu of carpet	66.6	$74	$4,928.40
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,698.00	$1,698.00
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	90	$26	$2,340.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
			$18,098.94
Design 14 (W2, W7, W4, T1, C3, W10)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Argon filled double glazed windows	18.51	$ 252	$4,664.52
R3.0 floor insulation			$2,200.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	90	$5.10	$459.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
Additional 50mm slab			$900.00
			$12,897.62

Design 15 (W2, R2, W11)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Triple glazing				$17,370
R6 floor insulation (labour)		86	$9	$774.00
R6 floor insulation (materials)		1	$3,348	$3,348.00
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		90	$26	$2,340.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
Extra brickwork				$720.00
				$28,782.24
Design 16 (W2, W4, W5, C7, T1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze timber		18.5	$300	$5,550.00
R3.0 floor insulation				$2,200.00
R5.0 ceiling insulation		110	$3.63	$399.30
R2.5 wall insulation		89	$5.10	$453.90
Addtional 100mm slab				$2,000
Tiles in lieu of carpet		66.6	$74	$4,928.40
				$14,878.00
Design 17 (W2, W4, C4, L1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R6 wall insulation				
150x 50 hwd studs		387	$5.32	$2,058.84
R4 rockwall		89	$26	$2,314.00
R2 polystyrene (labour and materials)		1	$1,439	$1,439.00
R8.0 ceiling insulation		110	$12.60	$1,386.00
R2.0 under slab				
Labour		1	$200.00	$200.00
Materials (31 sheets of EPS @$28.50 each)		31	$28.50	$883.50
				$11,885.04
Design 18 (W2, W4, C6, T1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
R10 wall insulation				$6,305
R12 ceiling insulation		110	$27.55	$3,030.50
Extra brickwork				$200.00
200 mm slab				$2,000
Tiles in lieu of carpet		66.6	$74	$4,928.40
				$22,410.60

Design 19 (W2, W8, R1,T1 150mm slab)	Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1040	$19,240.00
Single timber glazing elsewhere	5	$ 120.00	$600.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	89	$5.10	$453.90
R3.0 floor insulation			
Materials			$ 1,674.00
Labour			$ 645.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
150mm slab			$900.00
			$28,187.00
Design 20 (W2, W8, C7, T1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1020	$18,870.00
Single timber glazing elsewhere	5	$ 120.00	$600.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	89	$5.10	$453.90
R3.0 floor insulation			
Materials			$ 1,674.00
Labour			$ 645.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
200mm slab			$2,000
			$28,917.00
Design 21 (W2, W8, C7, T2)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1020	$18,870.00
Single timber glazing elsewhere	5	$ 120.00	$600.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	89	$5.10	$453.90
R3.0 floor insulation			
Materials			$ 1,674.00
Labour			$ 645.00
Tiles in lieu of carpet	43.3	$74	$3,204.20
Additional 100mm slab			$2,000
			$27,192.80
Design 22 (W2, W4, R4, L1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R10 floor insulation			
Labour	172	$4.50	$774.00
Materials 2x R4.0 EPS + 1 X R2.0 EPS=29 sheets X$64 + 29 sheets X$43	1	$4,959	$4,959.00
R10 wall insulation			$6,305
R12 ceiling insulation	110	$27.55	$3,030.50
Extra 360mm brickwork	6.84	$65	$444.60
			$19,116.80

Design 23 (W2, W8, R13, L1)	Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1020	$18,870.00
Single timber glazing elsewhere	10	$ 140.00	$1,400.00
R6 floor insulation (labour)	86	$9	$774.00
R6 floor insulation (materials)	1	$3,548	$3,548.00
R5.0 ceiling insulation	110	$3.63	$399.30
R2.5 wall insulation	89	$5.10	$453.90
			$24,791.60
Design 24 (W2, W4, R3, T1, L1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms	18.51	$230	$4,257.30
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,500.00	$1,500.00
R6 wall insulation			
150x 50 hwd studs	387	$5.32	$2,058.84
R4 rockwall	90	$26	$2,340.00
R2 polystyrene (labour and materials)	1	$1,439	$1,439.00
R8.0 ceiling insulation	110	$12.60	$1,386.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
			$17,900.94
Design 25 (W2, W4, C6, W5, T1)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Double glaze timber liv/dining and bedrooms	18.51	$300	$5,553.00
Timber single	5	$140.00	$700.00
Tiles in lieu of carpet	66.6	$74	$4,928.40
R10 wall insulation			$6,305
R12 ceiling insulation	110	$27.55	$3,030.50
Extra 360mm brickwork	6.84	$65	$444.60
R3.0 floor insulation (labour)	86	$7.50	$645.00
R3.0 floor insulation (materials)	1	$1,698.00	$1,698.00
Additional 100mm slab			$2,000
			$24,650.90
Design 26 (W2, R4, W8)			
Reduce south facing liv/din window and bedrooms windows	-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.	6.88	$195	$1,341.60
Triple glaze	18.5	1020	$18,870.00
Single timber glazing elsewhere	5	$ 120.00	$600.00
R10 floor insulation			
Labour	172	$4.50	$774.00
Materials	1	$4,700	$4,700.00
R10 wall insulation			$5,705
R12 ceiling insulation	110	$27.55	$3,030.50
Extra 360mm brickwork	6.84	$65	$444.60
			$33,470.50

Design 27 (W2, W4, C6, T1, W12)		Unit	Rate	Sub-total
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Double glaze liv/dining and bedrooms		18.51	$230	$4,257.30
Timber window frames		20.5	$140.00	$2,870.00
Tiles in lieu of carpet		66.6	$74	$4,928.40
R10 wall insulation				$5,900
R12 ceiling insulation		110	$27.55	$3,030.50
Extra 360mm brickwork		6.84	$65	$444.60
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
200mm slab				$2,000
				$4,380.00
				$29,500.20
Design 28 (W2, W8, C6, T1)				
Reduce south facing liv/din window and bedrooms windows		-6.88	$290	-$1,995.20
Extra bwk/ins/sis/plas/paint.		6.88	$195	$1,341.60
Triple glaze		18.5	1020	$18,870.00
Single timber glazing elsewhere		5	$ 120.00	$600.00
Tiles in lieu of carpet		66.6	$74	$4,928.40
R10 wall insulation				$6,305
R12 ceiling insulation		110	$27.55	$3,030.50
Extra 360mm brickwork		6.84	$65	$444.60
R3.0 floor insulation (labour)		86	$7.50	$645.00
R3.0 floor insulation (materials)		1	$1,698.00	$1,698.00
200mm slab				$2,000
				$37,867.90

Crimson: cost of design changes to achieve a rating of 5-6 stars

Design 1 (R2)	Unit	Rate	Sub-total
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
R8 roof insulation	144	$12.60	$1,814.40
			$14,133.82
Design 2 (R1)			
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	94	$ 5.10	$479.40
			$4,458.40
Design 3 (W2, R9)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$7,327.78
Design 4 (W2, W3, R7)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R2.5 in walls	101	$ 5.10	$515.10
R5 to ceiling			$540.00
			$4,504.95
Design 5 (W2, R1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	94	$ 5.10	$479.40
			$3,754.45
Design 6 (w1)			
Reduce window area	-14.97	290	-$4,341.30
Increase wall area	14.97	195	$2,919.15
			-$1,422.15

Design 7 (W1, C1)	Unit	Rate	Sub-total
Reduce window area	-14.97	290	-$4,341.30
Increase wall area	14.97	195	$2,919.15
R5 to ceiling			$540.00
R2.5 in walls	108	$ 5.10	$550.80
R1 slab insulation			$ 1,568.00
			$1,236.65
Design 8 (R12, R6, L1, W5)			
R2.5 in walls	94	$ 5.10	$479.40
R2.5 sub-floor			$1,922
Timber windows	42	$140	$5,880.00
			$8,281.40
Design 9 (W2, W3, R1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
			$7,943.95
Design 10			
(W2, R2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
R8 roof insulation	144	$12.60	$1,814.40
			$13,562.10
Design 11 (W2, W4, R1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
			$9,770.15

Design 12 (W2, W5, R9)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Timber windows	35	$ 140.00	$4,900.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall insulation	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$12,227.78

Crimson: cost of design changes to achieve a rating of 6-7 stars

Design 1 (W2, W4, R13)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
			$12,811.15
Design 2 (W2, W3, C1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
R1 slab insulation			$ 1,568.00
			$6,072.95

Design 3 (W2, C2)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
R1 slab insulation			$ 1,568.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$8,895.78
Design 4 (W2, R1, W3, W5)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze (timber)	18.06	$ 300.00	$5,418.00
Single glaze timber	23.3	$140	$3,262.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	94	$ 5.10	$479.40
			$12,434.45
Design 5 (W2, W4, C1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
R1 slab insulation			$ 1,568.00
			$7,899.15
Design 6 (W2, W4, R10)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R5 to ceiling			$540.00
R3 to slab			$ 3,439.00
			$13,488.55
Design 7 (W2, W4, R10, L1 + edge insulation)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R5 to ceiling			$540.00
R3 to slab			$ 3,439.00
			$13,488.55

Design 8 (W2, W3, R2)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
R8 roof insulation	144	$12.60	$1,814.40
			$17,715.90
Design 9 (W2, W3, C2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R1 slab insulation			$ 1,568.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$13,049.58
Design 10 (W9, C2)			
Reduce window area	-8.46	$290	-$2,453.40
Increase wall area	8.46	$195	$1,649.70
R1 slab insulation			$ 1,568.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$8,796.03

Design 11 (W2, W4, R2)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
R8 roof insulation	144	$12.60	$1,814.40
			$19,542.10
Design 12 (W1, W4, C7, T1)			
Reduce window area	-14.97	290	-$4,341.30
Increase wall area	14.97	195	$2,919.15
Double glaze	21.66	230	$4,981.80
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	94	$ 5.10	$479.40
100mm slab			$ 2,592.00
Tiles			$ 7,918.00
			$18,528.05
Design 13 (W2, W4, W5, R1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din (timber)	26	$ 300.00	$7,800.00
Timber windows	15	$140	$2,100.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
			$13,690.15
Design 14 (W2, W4, C2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R1 slab insulation			$ 1,568.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$14,875.78

Design 15 (W2, W4, C2 + edge insulation)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R1 slab insulation			$ 1,568.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	94	$18.89	$1,775.66
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$14,875.78
Design 16 (W2, W4, R11)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R8 floor			$8,138
R8 walls			$7,445
R10 ceiling			$3,060
Extra brickwork			$670
			$24,589.05
Design 17 (W2, W4, R1 , T1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
Tiles			$ 7,918.00
			$17,688.15
Design 18 (W2, W4, R1 , T1 + 100mm extra slab)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$20,280.15

Design 19 (W2, W4, C3 , T1)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
Tiles			$ 7,918.00
50mm slab			$ 1,296.00
			$18,984.15
Design 20 (W2, W4, R4)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R10 floor			$ 9,530.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
			$27,462.05
Design 21 (W2, W4, C4)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
			$15,940.01

Design 22 (W2, W4, C4, T1)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Tiles			$ 7,918.00
			$23,858.01
Design 23 (W2, W4, R1, T2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
Tiles			$ 6,430.00
			$16,200.15
Design 24 (W2, W4, C4, T2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Tiles			$ 6,430.00
			$22,370.01

Crimson- cost of design changes to achieve a rating of 7-8 stars

Design 1 (W2, W4, C4, T1)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
Tiles			$ 7,918.00
			$24,770.01
Design 2 (W2, W3, R3)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze	18.06	$ 230.00	$4,153.80
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
Addtional 100mm slab			$ 2,592.00
R3 Slab insulation			$ 3,260.00
			$18,377.81
Design 3 (W2, W4, C8)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
100mm slab			$ 2,592.00
R3 Slab insulation			$ 3,260.00
R8 walls			$ 7,280.00
R10 ceiling			$3,060
Extra brickwork			$912
			$22,380.05

Design 4 (W2, W4, W7, T1, C3)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Timber windows	29.49	$300	$8,847.00
Argon fill liv/din and beds windows	24.72	$22	$543.84
Tiles			$ 7,918.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
50mm slab			$ 1,296.00
			$22,394.99
Design 5 (W2, W8, R1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
R3 slab insulation	144.23	$ 21.00	$3,439.00
			$30,596.15
Design 6 (W2, W8, R14)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
R6 floor insulation			
Materials			$5,184
Labour			$1,296
			$33,637.15
Design 7 (W2, W4, C6)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R10 walls			$7,688
R12 ceiling			$3,542
Extra brickwork			$912
extra 100mm slab			$ 2,592.00
			$23,449.05

Design 8 (W2, W4, C5)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
R3 slab insulation	144.23	$ 21.00	$3,439.00
50mm slab			$ 1,296.00
			$22,667.05
Design 9 (W2, W4, C5 (100mm slab), T1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
R3 slab insulation	144.23	$ 21.00	$3,439.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$31,881.05
Design 10 (W2, W4, T1, C4 edge insulation)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
Tiles			$ 7,918.00
			$24,770.01

Design 11 (W2, W4, T1, C4, extra 100mm slab, edge insulation)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$27,362.01
Design 12 (W2, W4, R3, T1, extra 100mm slab, edge insulation)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
100mm slab			$ 2,592.00
R3 Slab insulation			$ 3,260.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$30,714.01
Design 13 (W2, R2, W11)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$18,889.00
R6 floor insulation			
Materials			$5,184
Labour			$1,296
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
R8 roof insulation	144	$12.60	$1,814.40
			$32,451.10

Design 14 (W2, W4, C4, L1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R2 slab insulation			$ 2,500.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
			$16,852.01
Design 15 (W2, W4, W7, T1, C3, W10)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Timber windows	29.49	$300	$8,847.00
Argon fill liv/din and beds windows	24.72	$22	$543.84
Tiles			$ 7,918.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
50mm slab			$ 1,296.00
			$22,394.99
Design 16 (W2, W4, R4, L1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R10 floor			$ 9,530.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
			$27,462.05

Design 17 (W2, W8, T1, C7)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
100mm slab			$ 2,592.00
Tiles			$ 7,918.00
			$41,106.15
Design 18 (W2, W8, C3, T1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
50mm slab			$ 1,296.00
Tiles			$ 7,918.00
			$39,810.15
Design 19 (W2, W4, W5, R1, T1 150mm slab)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din (timber)	26	$ 300.00	$7,800.00
Timber windows	15	$140	$2,100.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
50mm slab			$ 1,296.00
Tiles			$ 7,918.00
			$22,904.15
Design 20 (W2, W8, R14, L1)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
R6 floor insulation			
Materials			$5,184
Labour			$1,296
			$33,637.15

Design 21 (W2, W4, R3, T1 extra 100mm slab, L1 edge insulation)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din	26	$ 230.00	$5,980.00
R6 wall insulation			
150mm x 50mm frame	462	$5.32	$2,457.84
R4 Rockwall	101	$18.89	$1,907.89
R2 Polystyrene			
Materials	32	$34.56	$1,105.92
Labour	1	$500.00	$500.00
Extra wall ins	7.41	$51.00	$377.91
R8 roof insulation	144	$12.60	$1,814.40
Extra brickwork			$912.00
100mm slab			$ 2,592.00
R3 Slab insulation			$ 3,260.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$30,714.01
Design 22 (W2, W4, W5, T1, C5 extra 100mm slab)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Double glaze liv/din (timber)	26	$ 300.00	$7,800.00
Timber windows	15	$140	$2,100.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
R3 slab insulation	144.23	$ 21.00	$3,439.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$35,801.05

Design 23 (W2, W8, R4)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R10 floor			$ 9,530.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
			$48,288.05
Design 24 (W2, W4, W12, T1, C5 extra 100mm slab)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Thermal break/Double glaze liv/din	26	$ 500.00	$13,000.00
R10 walls			$7,688
extra wall insulation			$514
R12 ceiling			$3,542
Extra brickwork			$912
R3 slab insulation	144.23	$ 21.00	$3,439.00
Tiles			$ 7,918.00
100mm slab			$ 2,592.00
			$38,901.05
Design 25 (W2, W8, C6, T1)	Unit	Rate	Sub-total
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R10 walls			$7,688
R12 ceiling			$3,542
Extra brickwork			$912
extra 100mm slab			$ 2,592.00
Tiles			$ 7,918.00
			$52,193.05
Design 26 (W2, W8, C7, T2)			
Reduce window area	-7.41	$ 290.00	-$2,148.90
Increase wall area	7.41	$195	$1,444.95
Triple glaze			$26,806.00
R3 slab insulation	144.23	$ 21.00	$3,439.00
R5 to ceiling			$540.00
R2.5 in walls	101	$ 5.10	$515.10
Tiles			$ 6,430.00
			$37,026.15

Hickman: cost of design changes to achieve a rating of 5-6 stars

Design 1 (C9)		Unit	Rate	Sub-total
R1 slab insulation				**$ 1,426.00**
Design 2 (R6, R12, L1)				
R2.5 floor insulation		127	$ 13.35	$ 1,695.45
R2.5 walls		95	$5.10	$ 484.50
				$ 2,179.95
Design 3 (W3, W9)				
Reduce windows		11.76	$ (290.00)	$ (3,410.40)
Increase wall area		11.76	$195	$ 2,293.20
Double glaze		8.4	$230	$ 1,932.00
				$ 814.80
Design 4 (C1)				
R1 slab insulation				$ 1,426.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		95	$ 5.10	$ 484.50
				$ 2,519.51
Design 5 (R2)				
R6 floor insulation				
Materials				$ 4,590.00
Labour				$ 1,143.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		95	18.89	$ 1,794.55
R2 poly				
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 13,504.75
Design 6 (W1)				
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
				$ (2,063.40)
Design 7 (R1)				
R3.0 slab insulation				$2,941
R2.5 wall insulation		95	$ 5.10	$ 484.50
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
				$4,035
Design 8 (R4)				
R10 floor insulation				$ 8,325.00
R10 wall insulation				$ 10,550.00
R12 ceiling insulation				$ 3,857.00
				$ 22,732.00

Design 9 (W1, R8)		Unit	Rate	Sub-total
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
R 1.5 floor insulation		127	$ 12.80	$ 1,625.60
				$ (437.80)
Design 10 (W1, R6)				
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
R2.5 wall insulation		116	$ 5.10	$ 591.60
				$ (1,471.80)
Design 11 (W2, R1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
R3.0 slab insulation				$2,667
R2.5 wall insulation		106	$ 5.10	$ 540.60
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
				$ 2,750.71
Design 12 (W4, W1)				
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
Double glaze		15.33	$ 230.00	$ 3,525.90
				$ 1,462.50
Design 13 (W1, C1)				
R1 slab insulation				$ 1,426.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
				$ 563.21
Design 14 (W1, R7)				
Reduce windows		21.72	-$290	$ (6,298.80)
Add wall		21.72	$ 195.00	$ 4,235.40
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		106	$ 5.10	$ 540.60
				$ (913.79)

Hickman: cost of design changes to achieve a rating of 6-7 stars

Design 1 (R12, R6, L1, W5)	Unit	Rate	Sub-total
R2.5 wall insulation	116	$ 5.10	$ 591.60
R2.5 floor insulation	127	$ 13.35	$ 1,695.45
Timber windows	45	$140	$ 6,300.00
			$ 8,587.05
Design 2 (W2, R9)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	95	18.89	$ 1,794.55
R2 poly			
Extra insulation	11.22	65	$ 729.30
Materials			$ 1,140.00
Labour			$ 500.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
			$ 7,435.15
Design 3 (W2, R2)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
R6 floor insulation			
Materials			$ 4,590.00
Labour			$ 1,143.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	95	18.89	$ 1,794.55
R2 poly			
Materials			$ 1,140.00
Labour			$ 500.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
			$ 12,438.85
Design 4 (W2, W3, R1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
Double glaze	18.27	$230	$ 4,202.10
			$ 6,952.81

Design 5 (W2, W3, R7)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		18.27	$230	$ 4,202.10
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		106	$ 5.10	$ 540.60
				$ 4,285.81
Design 6 (W2, W4, R1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor insulation				$2,667
R2.5 wall insulation		106	$ 5.10	$ 540.60
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
				$ 8,730.71
Design 7 (W2, W4, R10)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor insulation				$2,667
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R4 wall insulation				$ 4,600.00
				$ 12,790.11
Design 8 (W2, W4, R13)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R5 floor insulation				
Materials				$ 3,672.00
Labour				$ 1,143.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 wall insulation		106	$ 5.10	$ 540.60
				$ 10,878.71
Design 9 (W2, W4, R13)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R5 floor insulation				
Materials				$ 3,672.00
Labour				$ 1,143.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 wall insulation		106	$ 5.10	$ 540.60
				$ 10,878.71

Design 10 (W2, W3, R2)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		18.27	$230	$ 4,202.10
R6 floor insulation				
Materials				$ 4,590.00
Labour				$ 1,143.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		95	18.89	$ 1,794.55
R2 poly				
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 16,640.95
Design 11 (W2, W5, R9)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Timber windows		33.78	$ 140.00	$ 4,729.20
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		95	18.89	$ 1,794.55
R2 poly				
Extra insulation		11.22	65	$ 729.30
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 12,164.35
Design 12 (W2, C2)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
R1 slab insulation				$ 1,426.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 poly				
Extra insulation		11.22	65	$ 729.30
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 9,050.05
Design 13 (W2, W3, C1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		18.27	$230	$ 4,202.10
R1 slab insulation				$ 1,426.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
				$ 5,762.81

Design 14 (W2, W4, R2)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R6 floor insulation				
Materials				$ 4,590.00
Labour				$ 1,143.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		95	18.89	$ 1,794.55
R2 poly				
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 18,418.85

Hickman: cost of design changes to achieve a rating of 7-8 stars

Design 1 (W2, W4, R10)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor insulation				$2,667
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R4 wall insulation				$ 4,780.00
				$ 12,970.11
Design 2 (W2, W4, C1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R1 slab insulation				$ 1,426.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
				$ 7,540.71
Design 3 (W2, W4, C7, T2)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
R3 floor insulation				$2,941
Extra 100mm slab				$2,286
Tiles				$ 1,133.00
				$ 12,474.71

Design 4 (W2, W4, W5, R1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Timber windows	33.78	140	$ 4,729.20
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 13,459.91
Design 5 (W1, W4, R4)			
Reduce windows	21.72	-$290	$ (6,298.80)
Add wall	21.72	$ 195.00	$ 4,235.40
Double glaze	15.33	$ 230.00	$ 3,525.90
R10 floor insulation			$ 9,900.00
R10 wall insulation			$ 10,550.00
R12 ceiling insulation			$ 3,857.00
			$ 25,769.50
Design 6 (W2, W4, C7, T1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Tiles			$ 3,066.00
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
R2.5 walls	116	$ 5.10	$ 591.60
R3 floor insulation			$2,941
Extra 100mm slab			$2,286
			$ 14,407.71
Design 7 (W1, W3, R9, C9)			
Reduce windows	21.72	-$290	$ (6,298.80)
Add wall	21.72	$ 195.00	$ 4,235.40
Double glaze	18.27	$ 230.00	$ 4,202.10
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
R1 slab insulation			$ 1,426.00
			$ 12,125.35

Design 8 (W2, W4, R1, T1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Tiles			$ 3,066.00
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
Tiles			$ 1,133.00
			$ 12,929.71
Design 9 (W1, W4, C2 edge insulation)			
Reduce windows	21.72	-$290	$ (6,298.80)
Add wall	21.72	$ 195.00	$ 4,235.40
Double glaze	15.33	$ 230.00	$ 3,525.90
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
R1 slab insulation			$ 1,426.00
			$ 11,449.15
Design 10 (W2, W11, R1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Triple glaze	25.83	$ 1,055	$ 27,250.65
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 30,001.36
Design 11 (W2, W4, R11, L1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R8 floor			
Materials			$ 5,504.00
Labour			$ 1,143.00
R8 walls			
Increase frame and R4 batts			$ 4,300.00
R4 polystyrene			
Materials			$ 2,112.00
Labour			$ 800.00
Extra wall area			$ 971.00
R10 ceiling			$ 2,699.00
Brickwork			$ 527.00
			$ 22,970.10

Design 12 (W2, W8, R14, L1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Triple glaze (timber)	26	1055	$ 27,430.00
R6.0 floor insulation			
R6 floor insulation			
Materials			$ 4,590.00
Labour			$ 1,143.00
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 33,246.71
Design 13 (W2, W4, T1, R1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Tiles			$ 3,066.00
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 11,796.71
Design 14 (W2, W4, C2)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
R1 slab insulation +edge			$ 1,426.00
			$ 14,900.75
Design 15 (W2, W4, C2 + edge)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
R1 slab insulation +edge			$ 1,426.00
			$ 14,900.75
Design 16 (W2, W4, C4)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R2 slab insulation			$ 2,160.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
			$ 15,634.75

Design 17 (W2, W4, R3, 200mm slab)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor insulation				$2,667
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 polystyrene				
Materials				$ 1,640.00
Labour				$ 600.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
Additional 100mm slab				$ 2,286.00
				$ 18,427.75
Design 18 (W2, W8, R4, L1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$1,055	$ 27,430.00
R10 floor insulation				$ 9,900.00
R10 wall insulation				$ 9,550.00
R12 ceiling insulation				$ 3,857.00
				$ 49,671.10
Design 19 (W2, W11, R2)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Triple glaze		18.27	$ 1,055	$ 19,274.85
R6 floor insulation				
Materials				$ 4,590.00
Labour				$ 1,143.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		95	18.89	$ 1,794.55
R2 poly				
Materials				$ 1,140.00
Labour				$ 500.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
				$ 31,713.70
Design 20 (W2, W4, C8)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor				$2,667
R8 walls				
Increase frame and R4 batts				$ 4,300.00
R4 polystyrene				
Materials				$ 2,112.00
Labour				$ 800.00
Extra wall area				$ 971.00
R10 ceiling				$ 2,699.00
Brickwork				$ 527.00
Additional 100mm slab				$ 2,286.00
				$ 21,276.10

Design 21 (W2, W4, C6)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor				$2,941
R10 wall insulation				$ 10,550.00
R12 ceiling insulation				$ 3,857.00
Additional 100mm slab				$ 2,286.00
				$ 24,548.10
Design 22 (W2, W4, C4, T2)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R2 slab insulation				$ 2,160.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 polystyrene				
Materials				$ 1,640.00
Labour				$ 600.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
Tiles				$ 1,133.00
				$ 16,767.75
Design 23 (W2, W4, C5)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3.0 slab insulation				$2,941
R10 wall insulation				$ 10,550.00
R12 ceiling insulation				$ 3,857.00
extra 50mm slab				$ 1,143.00
				$ 23,405.10
Design 24 (W2, W8, T2, C7)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Triple glaze (timber)		26	1055	$ 27,430.00
Tiles				$ 1,133.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
R3 floor insulation				$2,941
Extra 100mm slab				$2,286
				$ 33,924.71

Design 25 (W2, W4, C4, T1 edge insulation)		Unit	Rate	Sub-total
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R2 slab insulation				$ 2,160.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 polystyrene				
Materials				$ 1,640.00
Labour				$ 600.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
Tiles				$ 3,066.00
Edge insulation				$ 800.00
				$ 19,500.75
Design 26 (W2, W8, T1, C7)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Triple glaze (timber)		26	1055	$ 27,430.00
Tiles				$ 3,066.00
R5 ceiling insulation		127	$ 3.63	$ 461.01
Brickwork				$ 148.00
R2.5 walls		116	$ 5.10	$ 591.60
R3 floor insulation				$2,941
				$ 34,800.00
Design 27 (W2, W4, R3, T1, 200mm slab)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R3 floor insulation				$2,667
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 polystyrene				
Materials				$ 1,640.00
Labour				$ 600.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
Additional 100mm slab				$ 2,286.00
Tiles				$ 3,716.00
				$ 22,143.75
Design 28 (W2, W4, C4, T1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Double glaze		26	$230	$ 5,980.00
R2 slab insulation				$ 2,160.00
R6 wall insulation				
Studs (150 x 50mm)		450	$ 5.32	$ 2,394.00
R4 rockwall		105	18.89	$ 1,983.45
R2 polystyrene				
Materials				$ 1,640.00
Labour				$ 600.00
R8 ceiling		127	$12.60	$ 1,600.20
Brickwork				$ 343.00
Tiles				$ 3,716.00
				$ 19,350.75

Design 29 (W2, W4, C4, L1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R2 slab insulation			$ 2,160.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
			$ 15,634.75
Design 30 (W2, W4, C4, T1 and 150mm slab)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R2 slab insulation			$ 2,160.00
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
Tiles			$ 3,716.00
Addtional 50mm slab			$ 1,143.00
			$ 20,493.75
Design 31 (W2, T1, C7, W8)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Triple glaze	26	$ 1,055	$ 27,430.00
R3 floor insulation			$2,667
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
Additional 100mm slab			$ 2,286.00
Tiles			$ 3,716.00
			$ 36,182.71
Design 32 (W2, W8, R4, L1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Triple glaze	26	$1,055	$ 27,430.00
R10 floor insulation			$ 9,900.00
R10 wall insulation			$ 9,550.00
R12 ceiling insulation			$ 3,857.00
			$ 49,671.10

Design 33 (W2, W4, W7, R1, T1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Alumimium to timber windows	34	$ 140	$ 4,760.00
Argon fill	26	$ 22	$ 572.00
Tiles			$ 3,716.00
R3 floor insulation			$2,941
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 18,052.71
Design 34 (W2, W4, R3, T1 200mm slab + edge insulation)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R3 floor insulation			$2,667
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
Additional 100mm slab			$ 2,286.00
Tiles			$ 3,716.00
			$ 22,143.75
Design 35 (W2, W4, W5, T1, R1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Aluminium to timber windows	33.78	$ 140.00	$ 4,729.20
Tiles			$ 3,716.00
R3 floor insulation			$2,941
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
			$ 17,449.91

Design 36 (W2, W4, C6, T1)	Unit	Rate	Sub-total
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R3 floor			$2,941
R10 wall insulation			$ 10,550.00
R12 ceiling insulation			$ 3,857.00
Additional 100mm slab			$ 2,286.00
Tiles			$ 3,716.00
			$ 28,264.10
Design 37 (W2, W4, W7, W5, W10, R1, T1)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
Alumimium to timber windows	34	$ 140	$ 4,760.00
Argon fill	26	$ 22	$ 572.00
Tiles			$ 3,716.00
R3 floor insulation			$2,941
R2.5 wall insulation	106	$ 5.10	$ 540.60
R5 ceiling insulation	127	$ 3.63	$ 461.01
Brickwork			$ 148.00
Weatherstrip			$ 150.00
			$ 18,202.71
Design 38 (W2, W4, C6, T1, W5)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R3 floor			$2,941
R10 wall insulation			$ 10,550.00
R12 ceiling insulation			$ 3,857.00
Additional 100mm slab			$ 2,286.00
Tiles			$ 3,716.00
Alumimium to timber windows	34	$ 140	$ 4,760.00
			$ 33,024.10
Design 39 (W2, W4, R3, T1, L1 200mm slab + edge)			
Reduce windows	11.22	$ (290.00)	$ (3,253.80)
Add wall	11.22	$195	$ 2,187.90
Double glaze	26	$230	$ 5,980.00
R3 floor insulation			$2,667
R6 wall insulation			
Studs (150 x 50mm)	450	$ 5.32	$ 2,394.00
R4 rockwall	105	18.89	$ 1,983.45
R2 polystyrene			
Materials			$ 1,640.00
Labour			$ 600.00
R8 ceiling	127	$12.60	$ 1,600.20
Brickwork			$ 343.00
Additional 100mm slab			$ 2,286.00
Tiles			$ 3,716.00
			$ 22,143.75

Design 40 (W2, W8, C8, T1)				
Reduce windows		11.22	$ (290.00)	$ (3,253.80)
Add wall		11.22	$195	$ 2,187.90
Triple glaze		26	$1,055	$ 27,430.00
R3 floor				$2,667
R10 wall insulation				$ 10,550.00
R12 ceiling insulation				$ 3,857.00
Additional 100mm slab				$ 2,286.00
Tiles				$ 3,716.00
				$ 49,440.10

APPENDIX B- INCREASE IN ENERGY INTENSITY FROM THERMAL PERFOMANCE IMPROVEMENTS

Kingston: increase in energy intensity as a result of achieving a 5-6 star rating

Design 1 (W1, W4)	Unit	GJ	Sub-total	
Reduce glazing (single pane) in living/diningrom and bedrooms to 20% of wall area	-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation, studwork, plasterboard, paint)	13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)	-0.046	252.6	-11.62	
Double glaze new glazing area (extra pane)	12.07	2.44	29.45	
		TOTAL	**5.18**	**GJ**
Design 2 (W1, R6)				
Reduce glazing (single pane) in living/diningrom and bedrooms to 20% of wall area	-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation, studwork, plasterboard, paint)	13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)	-0.046	252.6	-11.62	
Additional R1.0 wall insulation	96	0.036	3.46	
		TOTAL	-20.82	**GJ**
Design 3 (L1, R8, R6)				
Subfloor insulation	86	0.13	11.18	
Sislation (insulation support)	86	0.14	11.78	
Addtional R1.0 wall insulation	83	0.036	2.99	
		TOTAL	**25.95**	**GJ**
Design 4 (R8, W1)				
Reduce glazing (single pane) in living/diningrom and bedrooms to 20% of wall area	-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation, studwork, plasterboard, paint)	13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)	-0.046	252.6	-11.62	
Subfloor insulation	86	0.13	11.18	
Sislation (insulation support)	86	0.14	11.78	
		TOTAL	**-1.31**	**GJ**

Design 5 (R12, R6, L1)					
Subfloor insulation		86	0.16	13.76	
Sislation (insulation support)		86	0.14	11.78	
Additional R1.0 wall insulation		96	0.036	3.46	
			TOTAL	**29.00**	**GJ**
Design 6 (W1,R7)		Unit	GJ	Sub-total	
Reduce glazing (single pane) in living/diningrom and bedrooms to 20% of wall area		-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation, studwork, plasterboard, paint)		13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)		-0.046	252.6	-11.62	
Additional R1.0 wall insulation		96	0.036	3.46	
Additional R1.5 ceiling insulation		97	0.13	12.61	
Addtional brickwork		1.44	0.594	0.86	
			TOTAL	-7.35	**GJ**
Design 7 (R1)					
Additional R1.0 wall insulation		83	0.036	2.99	
Additional R1.5 ceiling insulation		97	0.13	12.61	
Addtional brickwork		1.44	0.594	0.86	
R3 floor (poly)		86	0.866	74.48	
			TOTAL	**90.93**	**GJ**
Design 8 (R2)					
R6 floor insulation (poly)		172	0.58	99.07	
R4 wool wall insulation (diff bw R1.5 batts and R4 rockwall)		83	0.13	10.79	
R2 wall (poly)		83	0.58	47.89	
Extra framing (deeper studs)				8.9	
Extra R4.5 ceiling insulation		97	0.39	37.89	
Extra brickwork		8.6	0.59	5.10	
			TOTAL	**209.65**	**GJ**
Design 9 (W2) (R9)					
Glass reduced by 6.88m^2		-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.		6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg		-0.018	252.6	-4.55	
R4 wool wall insulation (diff bw R1.5 batts and R4		90	0.13	11.70	
R2 wall (poly)		90	0.58	51.93	
Extra framing (deeper studs)				8.9	
Extra R4.5 ceiling insulation		97	0.39	37.89	
Extra brickwork		8.6	0.59	5.10	
			TOTAL	**104.44**	**GJ**

Design 10 (R4)				
R10 floor insulation	86	2.82	242.52	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
		TOTAL	**478.21**	**GJ**
Design 11 (W1, C1)				
Reduce glazing (single pane) in living/diningrom and bedrooms to 20% of wall area	-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing (brickwork, sisalation, insulation, studwork, plasterboard, paint)	13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)	-0.046	252.6	-11.62	
Additional R1.0 wall insulation	96	0.036	3.46	
Additional R1.5 ceiling insulation	97	0.13	12.61	
R1 slab insulation (poly)	86	0.361	31.05	
		TOTAL	**22.84**	**GJ**
Design 12 (W2, W3, R7)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din	15.04	2.44	36.70	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
		TOTAL	**41.46**	**GJ**
Design 13 (W2, C2)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
R1 slab insulation (poly)	86	0.361	31.05	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**135.49**	**GJ**
Design 14 (R12, R6, L1, W5)				
Changed window frames to timber			-7.13	
Additional R1.0 wall insulation	90	0.036	3.24	
Subfloor insulation	86	0.16	13.76	
Sislation (insulation support)	86	0.14	11.78	
		TOTAL	**21.65**	**GJ**

Design 15 (W2, W5, R9)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Changed window frames to timber			-5.69	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**98.75**	**GJ**
Design 16 (W2, R2)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
R6 floor insulation (poly)	172	0.87	148.95	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**253.39**	**GJ**

Kingston: increase in energy intensity as a result of achieving a 6-7 star rating

Design 1 (W2, R1, W3)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din	15.04	2.44	36.70	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
		TOTAL	**116.80**	**GJ**
Design 2 (W9, W3, T1, C7)				
Single glazing reduced by 8.66m^2	-8.66	2.44	-21.13	
Reduction in window frame weight 32.71kg	-0.033	252.60	-8.34	
Extra bwk/ins/sis/plas/paint.	8.66	1.49	12.90	
Double glaze liv/din	9.19	$2	22.42	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100mm slab	10.8	4.00	43.24	
Tiles in lieu of carpet			-25.98	
		TOTAL	**114.30**	**GJ**

Design 3 (W9, W3, C2)				
Single glazing reduced by 8.66m^2	-8.66	2.44	-21.13	
Reduction in window frame weight 32.71kg	-0.033	252.60	-8.34	
Extra bwk/ins/sis/plas/paint.	8.66	1.49	12.90	
Double glaze liv/din	9.19	$2	22.42	
R1 slab insulation (poly)	86	0.288	24.77	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**146.15**	**GJ**
Design 4 (W2, R1, W4)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din and beds	18.5	2.44	45.14	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
		TOTAL	**125.24**	**GJ**
Design 5 (W2, W3, C1)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din	15.04	2.44	36.70	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
R1 slab insulation (poly)	86	0.288	24.77	
		TOTAL	**66.23**	**GJ**
Design 6 (W2, W4, C1)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din and beds	18.5	2.44	45.14	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
R1 slab insulation (poly)	86	0.288	24.77	
		TOTAL	**74.68**	**GJ**

Design 7 (W2, W4, R13)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din and beds	18.5	2.44	45.14	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
R5 floor insulation (poly)	86	$1.45	124.70	
		TOTAL	**174.61**	**GJ**
Design 8 (W2, W4, R10)				
Glass reduced by 6.88m^2	-6.9	2.4	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	0.0	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.4	45.1	
Additional R1.5 ceiling insulation	97.0	0.1	12.6	
R3 floor (poly)	86.0	0.9	74.5	
R4 wool wall insulation (diff bw R1.5 batts and R4	90.0	0.1	11.7	
Extra framing (deeper studs)			8.9	
		TOTAL	**141.74**	**GJ**
Design 9 (W2, W3, C2)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din	15.04	2.44	36.70	
R1 slab insulation (poly)	86	0.288	24.77	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**165.91**	**GJ**
Design 10 (W2, W4, C2)				
Glass reduced by 6.88m^2	-6.9	2.4	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	0.0	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.4	45.1	
R1 slab insulation (poly)	86	0.288	24.77	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**174.35**	**GJ**

Design 11 (W2, W4, C2)				
Glass reduced by 6.88m^2	-6.9	2.4	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	0.0	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.4	45.1	
R1 slab insulation (poly)	86	0.288	24.77	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**174.35**	**GJ**
Design 12 (W2, W3, R2)				
Glass reduced by 6.88m^2	-6.88	2.44	-16.79	
Extra bwk/ins/sis/plas/paint.	6.88	1.49	10.25	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.55	
Double glaze liv/din	15.04	2.44	36.70	
R6 floor insulation (poly)	172	0.87	148.95	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**290.09**	**GJ**
Design 13 (W4, W1, R5)				
Reduce glazing (single pane) in living/diningrom and	-13.32	2.44	-32.50	
Increase wall area to area reduction in glazing	13.32	1.49	19.85	
Reduction in aluminium framing (80.9kg to 35.26kg)	-0.046	252.6	-11.62	
Double glaze new glazing area (extra pane)	12.07	2.44	29.45	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
R5 floor insulation (poly)			125.10	
		TOTAL	**202.81**	**GJ**
Design 14 (W2, W4, R1, T1)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	0.0	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Tiles in lieu of carpet			-25.98	
		TOTAL	**99.25**	**GJ**

Design 15 (W2, W4, C3, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	0.0	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
		TOTAL	**120.88**	**GJ**
Design 16 (W2, W4, R2)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R6 floor insulation (poly)	172	0.87	148.95	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**298.53**	**GJ**
Design 17 (W2, W4, C7, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100 mm slab	10.8	4.00	43.24	
		TOTAL	**164.12**	**GJ**
Design 18 (W2, W4, C7, T2)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Tiles in lieu of carpet			-17.00	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100 mm slab	10.8	4.00	43.24	
		TOTAL	**151.48**	**GJ**

Design 19 (W2, W4, C4)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R4 wool wall insulation (diff bw R1.5 batts and R4 rockwall)	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
R2 floor (poly)	86	0.576	49.54	
		TOTAL	**199.12**	**GJ**
Design 20 (W2, W4, R3, W5)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Changed window frames to timber			-5.69	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
		TOTAL	**213.26**	**GJ**
Design 21 (W2, W4, R11)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R8 floor (poly)	86	2.3	197.80	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R4 wall (poly)	90	1.16	104.40	
Extra framing (deeper studs)			8.9	
Extra R6.5 ceiling insulation	97	0.56	54.61	
		TOTAL	**411.47**	**GJ**
Design 22 (W2, W4, R10)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4 rockwall)	90	0.13	11.70	
Extra framing (deeper studs)			8.9	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
		TOTAL	**142.6**	**GJ**

Kingston increase in energy intensity as a result of achieving a 7-8 star rating

Design 1 (W2, W8, R1)					
Glass reduced by 6.88m^2	-6.9	2.44	-16.8		
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3		
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5		
Triple glaze liv/din and beds	37.0	2.44	90.3		
Timber frame windows			-5.69		
Additional R1.0 wall insulation	90	0.036	3.24		
Additional R1.5 ceiling insulation	97	0.13	12.61		
Addtional brickwork	1.44	0.594	0.86		
R3 floor (poly)	86	0.866	74.48		
		TOTAL	**164.7**	**GJ**	
Design 2 (W2, W4, C4, T1)					
Glass reduced by 6.88m^2	-6.9	2.44	-16.8		
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3		
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5		
Double glaze liv/din and beds	18.5	2.44	45.1		
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70		
R2 wall (poly)	90	0.58	51.93		
Extra framing (deeper studs)			8.9		
Extra R4.5 ceiling insulation	97	0.39	37.89		
Extra brickwork	8.6	0.59	5.10		
R2 floor (poly)	86	0.576	49.54		
Tiles in lieu of carpet			-25.98		
		TOTAL	**173.1**	**GJ**	
Design 3 (W2, W4, C4, T2)					
Glass reduced by 6.88m^2	-6.9	2.44	-16.8		
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3		
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5		
Double glaze liv/din and beds	18.5	2.44	45.1		
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70		
R2 wall (poly)	90	0.58	51.93		
Extra framing (deeper studs)			8.9		
Extra R4.5 ceiling insulation	97	0.39	37.89		
Extra brickwork	8.6	0.59	5.10		
R2 floor (poly)	86	0.576	49.54		
Tiles in lieu of carpet			-17.00		
		TOTAL	**182.1**	**GJ**	
Design 4 (W2, W4, C4, T1 + extra 100mm slab)					
Glass reduced by 6.88m^2	-6.9	2.44	-16.8		
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3		
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5		
Double glaze liv/din and beds	18.5	2.44	45.1		
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70		
R2 wall (poly)	90	0.58	51.93		
Extra framing (deeper studs)			8.9		
Extra R4.5 ceiling insulation	97	0.39	37.89		
Extra brickwork	8.6	0.59	5.10		
R2 floor (poly)	86	0.576	49.54		
Tiles in lieu of carpet			-25.98		
Addtional 100 mm slab	10.8	4.00	43.24		
		TOTAL	**216.4**	**GJ**	

Design 5 (W2, W4, R4)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R10 floor insulation	86	2.88	247.68	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
		TOTAL	**517**	**GJ**
Design 6 (W2, W4, C4, T1 + extra 50 mm slab)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
R2 floor (poly)	86	0.576	49.54	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
		TOTAL	**194.75**	**GJ**
Design 7 (W2, W4, R3)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**224.06**	**GJ**
Design 8 (W2, W4, C6)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
		TOTAL	**387**	**GJ**

Design 9 (W2, W4, C8)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R4 wall (poly)	90	1.16	104.40	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**319.8**	**GJ**
Design 10 (W2, W4, C5)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
R3 floor (poly)	86	0.866	74.48	
Addtional 50 mm slab	5.4	4.00	21.62	
		TOTAL	**365.8**	**GJ**
Design 11 (W2, W8, R14)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
R6 floor (poly)	86	1.73	148.78	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
		TOTAL	**239.0**	**GJ**
Design 12 (W2, W4, W7, T1, C3)				
Glass reduced by $6.88m^2$	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Timber frame windows			-5.69	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
		TOTAL	**115.2**	**GJ**

Design 13 (W2, W4, R3, T1)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
Tiles in lieu of carpet			-25.98	
		TOTAL	**198.1**	**GJ**
Design 14 (W2, W7, W4, T1, C3, W10)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Timber frame windows			-5.69	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
		TOTAL	**115.19**	GJ
Design 15 (W2, R2, W11)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din	30	2.44	73.20	
Timber frame windows			-5.69	
R6 floor insulation (poly)	172	0.87	148.95	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
		TOTAL	**320.90**	**GJ**
Design 16 (W2, W4, W5, C7, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Timber frame windows			-5.69	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100 mm slab	10.8	4.00	43.24	
Tiles in lieu of carpet			-25.98	
		TOTAL	**136.8**	**GJ**

Design 17 (W2, W4, C4, L1)	Unit	GJ	Sub-total	
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
R2 floor (poly)	86	0.64	55.04	
		TOTAL	**204.62**	**GJ**
Design 18 (W2, W4, C6, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
Tiles in lieu of carpet			-25.98	
		TOTAL	**361.5**	GJ
Design 19 (W2, W8, R1,T1 150mm slab)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Tiles in lieu of carpet			-25.98	
Addtional 50 mm slab	5.4	4.00	21.62	
		TOTAL	**160.33**	**GJ**

Design 20 (W2, W8, C7, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100 mm slab	10.8	4.00	43.24	
Tiles in lieu of carpet			-25.98	
		TOTAL	**181.95**	**GJ**
Design 21 (W2, W8, C7, T2)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
Addtional brickwork	1.44	0.594	0.86	
R3 floor (poly)	86	0.866	74.48	
Addtional 100 mm slab	10.8	4.00	43.24	
Tiles in lieu of carpet			-17.00	
		TOTAL	**190.93**	**GJ**
Design 22 (W2, W4, R4, L1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R10 floor insulation	86	2.82	242.52	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
		TOTAL	**512.27**	**GJ**
Design 23 (W2, W8, R13, L1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
Additional R1.0 wall insulation	90	0.036	3.24	
Additional R1.5 ceiling insulation	97	0.13	12.61	
R5 floor insulation (poly)			125.10	
		TOTAL	**214.46**	**GJ**

Design 24 (W2, W4, R3, T1, L1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	90	0.13	11.70	
R2 wall (poly)	90	0.58	51.93	
Extra framing (deeper studs)			8.9	
Extra R4.5 ceiling insulation	97	0.39	37.89	
Extra brickwork	8.6	0.59	5.10	
Tiles in lieu of carpet			-25.98	
		TOTAL	**198.1**	**GJ**
Design 25 (W2, W4, C6, W5, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Timber frame windows			-5.69	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
Tiles in lieu of carpet			-25.98	
		TOTAL	**355.8**	**GJ**
Design 26 (W2, R4, W8)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Triple glaze liv/din and beds	37.0	2.44	90.3	
Timber frame windows			-5.69	
R10 floor insulation	86	2.88	247.68	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
		TOTAL	**556.9**	**GJ**

Design 27 (W2, W4, C6, T1, W12)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
Tiles in lieu of carpet			-25.98	
		TOTAL	**361.49**	**GJ**
Design 28 (W2, W8, C6, T1)				
Glass reduced by 6.88m^2	-6.9	2.44	-16.8	
Extra bwk/ins/sis/plas/paint.	6.9	1.5	10.3	
Aluminium frames reduced by 18.42kg	-0.018	252.6	-4.5	
Double glaze liv/din and beds	18.5	2.44	45.1	
Addtional 100 mm slab	10.8	4.00	43.24	
R3 floor (poly)	86	0.866	74.48	
R4 wool wall insulation (diff bw R1.5 batts and R4	83	0.13	10.79	
Extra framing (deeper studs)			8.9	
R6 wall (poly)	83	1.69	140.19	
Addtional R8.5 ceiling insulation	97	0.74	71.78	
Addtional brickwork	6.84	0.59	4.04	
Tiles in lieu of carpet			-25.98	
		TOTAL	**361.49**	**GJ**

Crimson- increase in energy intensity as a result of achieving a 5-6 star rating

Design 1 (R2)	Qty	Rate	Sub-total	
R6 floor insulation	114	1.688	192.4	
R4 wall insulation (rockwall)	94	0.13	12.2	
R2 wall (poly)	94	0.58	54.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**335**	**GJ**
Design 2 (R1)				
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	94	0.03	3.1	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**121.61**	**GJ**
Design 3 (W2, R9)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**136.5**	**GJ**
Design 4 (W2, W3, R7)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**53.0**	**GJ**

Design 5 (W2, R1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**107.09**	**GJ**
Design 6 (w1)				
Reduce aluminium frames			-14.26	
Reduce single glazing	-14.97	2.44	-36.5	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	14.97	1.49	22.3	
			-28.48	**GJ**
Design 7 (W1, C1)				
Reduce aluminium frames			-14.26	
Reduce single glazing	-14.97	2.44	-36.5	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	14.97	1.49	22.3	
R1 floor insulation	114	0.29	32.8	
R2.5 wall (rockwool) (diff between base case)	120	0.03	4.0	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**28.8**	**GJ**
Design 8 (R12, R6, L1, W5)				
Timber in lieu of aluminium windows			-21	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
R2.5 floor insulation	114	0.22	25.1	
Sislation (insulation support)	114	0.14	16.0	
		TOTAL	**23.5**	**GJ**

Design 9 (W2, W3, R1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**151**	**GJ**
Design 10				
(W2, R2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
R6 floor insulation	114	1.73	197.2	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**333.7**	**GJ**
Design 11 (W2, W4, R1)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**168.1**	**GJ**
Design 12 (W2, W5, R9)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Timber in lieu of alumnium frames			-21	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**115.5**	**GJ**

Crimson: increase in energy intensity as a result of achieving a 6-7 star rating

Design 1 (W2, W4, R13)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R5.0 floor insulation	114	1.44	164.2	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**234.21**	**GJ**
Design 2 (W2, W3, C1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R1 floor insulation	114	0.29	32.8	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**85.8**	**GJ**
Design 3 (W2, C2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R1 floor insulation	114	0.29	32.8	
		TOTAL	**169.3**	**GJ**

Design 4 (W2, R1, W3, W5)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**130.0**	**GJ**
Design 5 (W2, W4, C1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R1 floor insulation	114	0.29	32.8	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**102.9**	**GJ**
Design 6 (W2, W4, R10)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R4 wall insulation (rockwall)	116	0.13	15.1	
Extra framing (deeper studs)			16	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**195.7**	**GJ**

Design 7 (W2, W4, R10, L1 + edge insulation)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R4 wall insulation (rockwall)	116	0.13	15.1	
Extra framing (deeper studs)			16	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**195.7**	**GJ**
Design 8 (W2, W3, R2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R6 floor insulation	114	1.73	197.2	
R4 wall insulation (rockwall)	94	0.13	12.2	
R2 wall (poly)	94	0.58	54.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**369.1**	**GJ**
Design 9 (W2, W3, C2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R1 floor insulation	114	0.29	32.8	
		TOTAL	**213.21**	**GJ**

Design 10 (W9, C2)				
Windows reduced by 28.71kg			-7.32	
Single glazing reduced	-8.46	2.44	-20.6	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	8.46	1.49	12.6	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R1 floor insulation	114	0.29	32.8	
		TOTAL	**168.8**	**GJ**
Design 11 (W2, W4, R2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R6 floor insulation	114	1.73	197.2	
R4 wall insulation (rockwall)	94	0.13	12.2	
R2 wall (poly)	94	0.58	54.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**386.2**	**GJ**
Design 12 (W1, W4, C7, T1)				
Reduce aluminium frames			-14.26	
Reduce single glazing	-14.97	2.44	-36.5	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	14.97	1.49	22.3	
Double glaze liv/din and beds	21	2.44	51.2	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 100mm slab	14.4	4.00	57.60	
Tiles in lieu of carpet			-41.7	
		TOTAL	**161**	**GJ**

Design 13 (W2, W4, W5, R1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**147.1**	**GJ**
Design 14 (W2, W4, C2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R1 floor insulation	114	0.29	32.8	
		TOTAL	**230.3**	**GJ**
Design 15 (W2, W4, C2 + edge insulation)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R1 floor insulation	114	0.29	32.8	
		TOTAL	**230.3**	**GJ**

Design 16 (W2, W4, R11)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R8 floor insulation	114	2.3	262.2	
R4 wall insulation (rockwall)	106	0.13	13.8	
R4 wall (poly)	106	1.16	123.0	
Extra framing (deeper studs)			16	
Addtional R6.5 ceiling insulation	144	0.56	80.6	
Addtional brickwork			8.26	
		TOTAL	**549.93**	**GJ**
Design 17 (W2, W4, R1 , T1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Tiles in lieu of carpet			-41.7	
		TOTAL	**126.4**	**GJ**
Design 18 (W2, W4, R1 , T1 + 100mm extra slab)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Tiles in lieu of carpet			-41.7	
Additional 100mm slab	14.4	4.00	57.6	
		TOTAL	**184.0**	**GJ**

Design 19 (W2, W4, C3 , T1)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 50mm slab	7.2	4.00	28.80	
Tiles in lieu of carpet			-41.7	
		TOTAL	**155.2**	**GJ**
Design 20 (W2, W4, R4)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R10 floor (poly)	114	2.88	328.3	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
		TOTAL	**702.3**	**GJ**
Design 21 (W2, W4, C4)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**263.58**	**GJ**

Design 22 (W2, W4, C4, T1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
Tiles in lieu of carpet			-41.7	
		TOTAL	**221.8**	**GJ**
Design 23 (W2, W4, R1, T2)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Tiles in lieu of carpet			-34.0	
		TOTAL	**134.1**	**GJ**
Design 24 (W2, W4, C4, T2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-34.0	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**233.18**	**GJ**

Crimson: increase in energy intensity as a result of achieving a 7-8 star rating

Design 1 (W2, W4, C4, T1)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-41.7	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**225.4**	**GJ**
Design 2 (W2, W3, R3)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double glaze liv/din	18	2.44	43.9	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
Extra framing (deeper studs)			16	
		TOTAL	**196.4**	**GJ**
Design 3 (W2, W4, C8)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R4 wall insulation (rockwall)	106	0.13	13.8	
R4 wall (poly)	106	1.15	121.9	
Extra framing (deeper studs)			16	
R3.0 floor insulation	114	0.86	98.0	
Addtional 100mm slab	14.4	4.00	57.60	
Addtional R6.5 ceiling insulation	144	0.56	80.6	
Addtional brickwork			8.26	
		TOTAL	**442.3**	**GJ**

Design 4 (W2, W4, W7, T1, C3)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-41.7	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 50mm slab	7.2	4.00	28.80	
		TOTAL	**137.8**	**GJ**
Design 5 (W2, W8, R1)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**208.1**	**GJ**
Design 6 (W2, W8, R14)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R6.0 floor insulation	114	1.73	197.2	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**307.3**	**GJ**

Design 7 (W2, W4, C6)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Addtional 100mm slab	14.4	4.00	57.60	
R3.0 floor insulation	114	1.72	196.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
		TOTAL	**627.6**	**GJ**
Design 8 (W2, W4, C5)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
Addtional 50mm slab	7.2	4.00	28.80	
		TOTAL	**500.8**	**GJ**
Design 9 (W2, W4, C5 (100mm slab), T1)	Qty	Rate	Sub-total	
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R3.0 floor insulation	114	0.86	98.0	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
Tiles in lieu of carpet			-41.7	
		TOTAL	**430.3**	**GJ**

Design 10 (W2, W4, T1, C4 edge insulation)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-41.7	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**221.8**	**GJ**
Design 11 (W2, W4, T1, C4, extra 100mm slab, edge insulation)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-41.7	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
Addtional 100mm slab	14.4	4.00	57.60	
		TOTAL	**279.4**	**GJ**
Design 12 (W2, W4, R3, T1, extra 100mm slab, edge insulation)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-41.7	
Addtional 100mm slab	14.4	4.00	57.60	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R3.0 floor insulation	114	0.86	98.0	
		TOTAL	**311.4**	**GJ**

Design 13 (W2, R2, W11)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple glaze liv/din	18	4.88	87.8	
Timber in lieu of alumnium frames			-21	
R6 floor insulation	114	1.73	197.2	
R4 wall insulation (rockwall)	94	0.13	12.2	
R2 wall (poly)	94	0.58	54.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**392.0**	**GJ**
Design 14 (W2, W4, C4, L1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R2 floor insulation	114	0.58	66.1	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
		TOTAL	**263.6**	**GJ**
Design 15 (W2, W4, W7, T1, C3, W10)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-41.7	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 50mm slab	7.2	4.00	28.80	
		TOTAL	**134.2**	**GJ**

Design 16 (W2, W4, R4, L1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
R10 floor (poly)	114	2.88	328.3	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
		TOTAL	**702.3**	**GJ**
Design 17 (W2, W8, T1, C7)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 100mm slab	14.4	4.00	57.60	
Tiles in lieu of carpet			-41.7	
		TOTAL	**224.0**	**GJ**
Design 18 (W2, W8, C3, T1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 50mm slab	7.2	4.00	28.80	
Tiles in lieu of carpet			-41.7	
		TOTAL	**195.2**	**GJ**

Design 19 (W2, W4, W5, R1, T1 150mm slab)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 50mm slab	7.2	4.00	28.80	
Tiles in lieu of carpet			-41.7	
		TOTAL	**134.2**	**GJ**
Design 20 (W2, W8, R14, L1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R6.0 floor insulation	114	1.72	196.1	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
		TOTAL	**306.1**	**GJ**
Design 21 (W2, W4, R3, T1 extra 100mm slab, L1 edge insulation)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Double-glaze liv/din and beds	25	2.44	61.0	
Tiles in lieu of carpet			-41.7	
Addtional 100mm slab	14.4	4.00	57.60	
R4 wall insulation (rockwall)	106	0.13	13.8	
R2 wall (poly)	106	0.58	61.5	
Extra framing (deeper studs)			16	
Additonal R4.5 ceiling	144	0.39	56.2	
Addtional brickwork	6.7	0.59	4.0	
R3.0 floor insulation	114	0.86	98.0	
		TOTAL	**311.4**	**GJ**

Design 25 (W2, W8, C6, T1)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
Addtional 100mm slab	14.4	4.00	57.60	
R3.0 floor insulation	114	1.73	197.2	
R4 wall insulation (rockwall)	106	0.13	13.8	
R6 wall (poly)	106	1.74	184.4	
Extra framing (deeper studs)			16	
Additional R8.5 ceiling	144	0.74	106.6	
Addtional brickwork	12	0.59	7.1	
Tiles in lieu of carpet			-41.7	
		TOTAL	**627.0**	**GJ**
Design 26 (W2, W8, C7, T2)				
Reduction in aluminium frames			-3.60	
Reduction in single glazing area	-11.91	2.44	-29.1	
Increase in wall area (extra bwk/sis/stud/ins/plast/paint)	11.91	1.49	17.7	
Triple-glaze liv/din and beds	25	4.88	122.0	
Timber in lieu of alumnium frames			-21	
R3.0 floor insulation	114	0.86	98.0	
R2.5 wall (rockwool) (diff between base case)	106	0.03	3.5	
Additional R1.5 ceiling	144	0.13	18.7	
Addtional brickwork	2.96	0.59	1.7	
Addtional 100mm slab	14.4	4.00	57.60	
Tiles in lieu of carpet			-34.0	
		TOTAL	**231.7**	**GJ**

Hickman: increase in energy intensity as a result of achieving a 5-6 star rating

Design 1 (C9)	Qty	Rate	Sub-total	
R1.0 floor insulation	127	0.288	**36.58**	**GJ**
Design 2 (R6, R12, L1)				
R2.5 floor insulation	127	0.22	27.94	
Sisalation	127	0.14	17.78	
R2.5 rockwall walls (diff bw base case)	95	0.03	3.14	
		TOTAL	**48.86**	**GJ**
Design 3 (W3, W9)				
Reduction in aluminium frames			-17.50	
Reduction in single glazing	-11.76	2.44	-28.69	
Additional bwk/sis/ins/plas/paint	11.76	1.49	17.52	
Double/glaze liv/din	8.4	2.44	20.50	
		TOTAL	**-8.18**	**GJ**
Design 4 (C1)				
R1 slab insulation	127	0.288	36.58	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 walls	95	0.03	3.14	
		TOTAL	**57.57**	**GJ**
Design 5 (R2)				
R6 floor insulation	127	1.73	219.71	
R4 wall insulation (rockwall)	95	0.13	12.35	
R2 wall (poly)	95	0.58	55.10	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**350.03**	**GJ**
Design 6 (W1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
		TOTAL	**-44.65**	**GJ**
Design 7 (R1)				
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	95	0.03	3.14	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**128.9**	**GJ**

Design 8 (R4)				
R10 slab insulation	127	2.88	365.76	
R4 wall insulation (rockwall)	95	0.13	12.35	
R6 wall (poly)	95	1.74	165.30	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
		TOTAL	**653.7**	**GJ**
Design 9 (W1, R8)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
R1.5 floor insulation	127	0.13	16.76	
Sisalation	127	0.14	17.78	
		TOTAL	**-10.11**	**GJ**
Design 10 (W1, R6)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
		TOTAL	**-40.83**	**GJ**
Design 11 (W2, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
		TOTAL	**109**	**GJ**
Design 12 (W4, W1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
		TOTAL	**-7.25**	**GJ**
Design 13 (W1, C1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
R1 slab insulation	127	0.288	36.58	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 walls	116	0.03	3.83	
		TOTAL	**13.61**	**GJ**

Design 14 (W1, R7)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
R2.5 walls	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**-22.97**	**GJ**

Hickman: increase in energy intensity as a result of achieving a 6-7 star rating

Design 1 (R12, R6, L1, W5)				
R2.5 floor insulation	127	0.22	27.94	
Sisalation	127	0.14	17.78	
R2.5 rockwall walls (diff bw base case)	95	0.03	3.14	
Timber in lieu of aluminium frames			-23.00	
		TOTAL	**25.86**	**GJ**
Design 2 (W2, R9)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**117.62**	**GJ**
Design 3 (W2, R2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
R6 floor insulation	127	1.73	219.71	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**337.33**	**GJ**

Design 4 (W2, W3, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din	20.16	2.44	49.19	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**159.3**	**GJ**
Design 5 (W2, W3, R7)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din	20.16	2.44	49.19	
R2.5 walls	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**50.03**	**GJ**
Design 6 (W2, W4, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**173.0**	**GJ**
Design 7 (W2, W4, R10)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	106	0.13	13.78	
Extra framing (deeper studs)			10.22	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**193.47**	**GJ**

Design 8 (W2, W4, R13)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R5 floor insulation	127	1.43	181.61	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
		TOTAL	**245**	**GJ**
Design 9 (W2, W4, R13)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R5 floor insulation	127	1.43	181.61	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
		TOTAL	**245**	**GJ**
Design 10 (W2, W3, R2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din	20.16	2.44	49.19	
R6 floor insulation	127	1.73	219.71	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**387**	**GJ**
Design 11 (W2, W5, R9)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Timber in lieu of alumInium frames			-21	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**97**	**GJ**

Design 12 (W2, C2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**154**	**GJ**
Design 13 (W2, W3, C1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din	20.16	2.44	49.19	
R1 slab insulation	127	0.288	36.58	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 walls	106	0.03	3.50	
		TOTAL	**87**	**GJ**
Design 14 (W2, W4, R2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R6 floor insulation	127	1.73	219.71	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**400**	**GJ**

Hickman: increase in energy intensity as a result of achieving a 7-8 star rating

Design 1 (W2, W4, R10)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	106	0.13	13.78	
Extra framing (deeper studs)			10.22	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**193**	**GJ**
Design 2 (W2, W4, C1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R1 slab insulation	127	0.288	36.58	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R2.5 walls	106	0.03	3.50	
		TOTAL	**100**	**GJ**
Design 3 (W2, W4, C7, T2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-16.00	
		TOTAL	**208**	**GJ**
Design 4 (W2, W4, W5, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
Timber in lieu of alumnium frames			-21	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**152**	**GJ**

Design 5 (W1, W4, R4)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R10 slab insulation	127	2.88	365.76	
R4 wall insulation (rockwall)	115	0.13	14.95	
R6 wall (poly)	115	1.74	200.10	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
		TOTAL	**684**	**GJ**
Design 6 (W2, W4, C7, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**194**	**GJ**
Design 7 (W1, W3, R9, C9)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din	18.27	2.44	44.58	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**182**	**GJ**
Design 8 (W2, W4, R1, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**143**	**GJ**

Design 5 (W1, W4, R4)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R10 slab insulation	127	2.88	365.76	
R4 wall insulation (rockwall)	115	0.13	14.95	
R6 wall (poly)	115	1.74	200.10	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
		TOTAL	**684**	**GJ**
Design 6 (W2, W4, C7, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**194**	**GJ**
Design 7 (W1, W3, R9, C9)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din	18.27	2.44	44.58	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**182**	**GJ**

Design 8 (W2, W4, R1, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**143**	**GJ**
Design 9 (W1, W4, C2 edge insulation)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**175**	**GJ**
Design 10 (W2, W11, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din	20.16	4.88	98.38	
Timber in lieu of alumnium frames			-21	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**187**	**GJ**

Design 11 (W2, W4, R11, L1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R8 floor insulation	127	2.3	292.10	
R4 wall insulation (rockwall)	116	0.13	15.08	
R4 wall (poly)	116	1.16	134.56	
Extra framing (deeper studs)			10.22	
Additional R6.5 ceiling	127	0.56	71.12	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**519**	**GJ**
Design 12 (W2, W8, R14, L1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
R6 floor insulation	127	1.73	219.71	
		TOTAL	**325**	**GJ**
Design 13 (W2, W4, T1, R1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**94**	**GJ**
Design 14 (W2, W4, C2)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**175**	**GJ**

Design 15 (W2, W4, C2 + edge)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R1 slab insulation	127	0.288	36.58	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**175**	**GJ**
Design 16 (W2, W4, C4)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**212**	**GJ**
Design 17 (W2, W4, R3, 200mm slab)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 slab insulation	127	0.87	110.49	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
		TOTAL	**299**	**GJ**

Design 18 (W2, W8, R4, L1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
R10 slab insulation	127	2.88	365.76	
R4 wall insulation (rockwall)	105	0.13	13.65	
R6 wall (poly)	105	1.74	182.70	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
		TOTAL	**757**	**GJ**
Design 19 (W2, W11, R2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din	20.16	4.88	98.38	
Timber in lieu of alumnium frames			-21	
R6 floor insulation	127	1.73	219.71	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**415**	**GJ**
Design 20 (W2, W4, C8)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	116	0.13	15.08	
R4 wall (poly)	116	1.16	134.56	
Extra framing (deeper studs)			10.22	
Additional R6.5 ceiling	127	0.56	71.12	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
		TOTAL	**387**	**GJ**

Design 21 (W2, W4, C6)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	105	0.13	13.65	
R6 wall (poly)	105	1.74	182.70	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
Addtional 100mm slab			51.00	
		TOTAL	**460**	**GJ**
Design 22 (W2, W4, C4, T2)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
Tiles in lieu of carpet			-14.00	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**240**	**GJ**
Design 23 (W2, W4, C5)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 slab insulation	127	0.864	109.73	
R4 wall insulation (rockwall)	106	0.13	13.78	
R6 wall (poly)	106	1.74	184.44	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
Additional 50mm slab			26.00	
		TOTAL	**487**	**GJ**

Design 24 (W2, W8, T2, C7)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Tiles in lieu of carpet			-14.00	
Timber in lieu of alumnium frames			-21	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
		TOTAL	**252**	**GJ**
Design 25 (W2, W4, C4, T1 edge insulation)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	106	0.13	13.78	
R2 wall (poly)	106	0.58	61.48	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Tiles in lieu of carpet			-30.00	
		TOTAL	**224**	**GJ**
Design 26 (W2, W8, T1, C7)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
		TOTAL	**236**	**GJ**

Design 27 (W2, W4, R3, T1, 200mm slab)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 slab insulation	127	0.87	110.49	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**269**	**GJ**
Design 28 (W2, W4, C4, T1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Tiles in lieu of carpet			-30.00	
		TOTAL	**182**	**GJ**
Design 29 (W2, W4, C4, L1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
		TOTAL	**212**	**GJ**

Design 30 (W2, W4, C4, T1 and 150mm slab)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R2 slab insulation	127	0.58	73.66	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Tiles in lieu of carpet			-30.00	
Addtional 50mm slab			26.00	
		TOTAL	**208**	**GJ**
Design 31 (W2, T1, C7, W8)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	106	0.03	3.50	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**236**	**GJ**
Design 32 (W2, W8, R4, L1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
R10 slab insulation	127	2.88	365.76	
R4 wall insulation (rockwall)	106	0.13	13.78	
R6 wall (poly)	106	1.74	184.44	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
		TOTAL	**759**	**GJ**

Design 33 (W2, W4, W7, R1, T1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**73**	**GJ**
Design 34 (W2, W4, R3, T1 200mm slab + edge insulation)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 slab insulation	127	0.87	110.49	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**269**	**GJ**
Design 35 (W2, W4, W5, T1, R1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**122**	**GJ**

Design 36 (W2, W4, C6, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Double glaze liv/din and beds	25.78	2.44	62.90	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	105	0.13	13.65	
R6 wall (poly)	105	1.74	182.70	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**479**	**GJ**
Design 37 (W2, W4, W7, R1, T1)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
Timber in lieu of alumnium frames			-21	
Tiles in lieu of carpet			-30.00	
R3 slab insulation	127	0.86	109.22	
R2.5 rockwall walls (diff bw base case)	116	0.03	3.83	
Addtional R1.5 ceiling	127	0.13	16.51	
Additional brickwork	2.28	0.59	1.35	
		TOTAL	**73**	**GJ**
Design 38 (W2, W4, C6, T1, W5)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
Timber in lieu of alumnium frames			-21	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	105	0.13	13.65	
R6 wall (poly)	105	1.74	182.70	
Extra framing (deeper studs)			10.22	
Additional R8.5 ceiling insulation	127	0.738	93.73	
Extra brickwork	10.8	0.59	6.37	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**409**	**GJ**

Design 39 (W2, W4, R3, T1, L1 200MM slab + edge)				
Reduction in alumunium frames			-24.00	
Single glazing reduced	-21.74	2.44	-53.05	
Additional bwk/sis/ins/plas/paint	21.74	1.49	32.39	
Double glaze liv/din and beds	15.33	2.44	37.41	
R3 slab insulation	127	0.87	110.49	
R4 wall insulation (rockwall)	116	0.13	15.08	
R2 wall (poly)	116	0.58	67.28	
Extra framing (deeper studs)			10.22	
Additional R4.5 ceiling	127	0.39	49.53	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**269**	**GJ**
Design 40 (W2, W8, C8, T1)				
Reduction in alumunium frames			-9.85	
Single glazing reduced	-11.22	2.44	-27.38	
Additional bwk/sis/ins/plas/paint	11.22	1.49	16.72	
Triple glaze liv/din and beds	25.78	4.88	125.81	
Timber in lieu of alumnium frames			-21	
R3 floor insulation	127	0.86	109.22	
R4 wall insulation (rockwall)	116	0.13	15.08	
R4 wall (poly)	116	1.16	134.56	
Extra framing (deeper studs)			10.22	
Additional R6.5 ceiling	127	0.56	71.12	
Additional brickwork	5.28	0.59	3.12	
Addtional 100mm slab			51.00	
Tiles in lieu of carpet			-30.00	
		TOTAL	**449**	**GJ**

APPENDIX C- ENERGY INTENSITY OF BASE CASE HOUSES

Kingston Slab-on-Ground - Process based energy intensity

	Quantity	Energy intensity/unit	Total Energy Intensity
SUBSTRUCTURE			
Preliminaries			
Membrane (0.2mm) m2	120	0.103	12.360
Sand (m3)	6	0.617	3.702
100 thick concrete slab	10.4	4.004	41.642
Concrete footings and thickenings	17	4.004	68.068
Steel mesh (SL72) 8 sheets	0.32	85.463	27.348
Trench mesh (17 sheets)	0.379	85.463	32.390
Paint (3 coats)	249	0.096	23.904
ROOF			
Timber truss	1.9	10.925	20.758
steel fixings 22 x1.314kg (per truss)	0.03	85.463	2.564
Battens	0.46	21.326	9.810
Colorbond roofing (cost inlcudes insulation)	130	0.588	76.440
Ridge flashing (65 lm)	16.25	0.588	9.555
Insulation (R3.5 glass fibre)	97	0.3	29.100
Sisalation	130	0.137	17.810
Gutters (49 lm)	13	0.588	7.644
PVC Downpipes	10	0.266	2.660
eaves lining	23	0.288	6.624
Paint (3 coats)	69	0.096	6.624
Colorbond fascia (49 lm)	9.8	0.588	5.762
eaves lining framing	0.08	10.925	0.874
EXTERNAL WALLS			
brickwork	83	0.56	46.480
0.05kg of wall ties per m2 (83 x 0.05)	0.00415	85.463	0.355
mortar (about 6% of brickwork per m2)	83		2.800
Stud frame (m3) (cost incl. ins and sis)	1.24	10.925	13.547
Lintels	0.09	21.326	1.919
Nails for framing (6kg/per m3 of timber)	0.008	85.463	0.684
ply bracing			
Tie down straps			
Insulation (R1.5 rockwall)	83	0.13	10.790
Building wrap (assume zero for fixings)	83	0.137	11.371
Plasterboard (assume zero for fixings and glue	83	0.207	17.181
WINDOWS AND DOORS			
Frames	0.108	252.605	27.281
single glazed	27.38	2.44	66.807
double glazed (4mm)		2.44	0.000
Double glazed (3mm)		1.83	0.000
Timber entry door (.0075m3)	0.0075	21.326	0.160
Garage door (1 off) steel frame excluded	6.75	0.588	3.969
Paint entry door	10	0.096	0.960
INTERNAL WALLS			
Stud wall (m3)	0.9	10.925	9.833
Nails for framing (6kg/m3 of timber)	0.0054	85.463	0.462
Plasterboard (68 x 2 check)	136	0.207	28.152
Paint (68 x 2) 3 coats	408	0.096	39.168
INTERNAL DOORS			
Timber hollow core doors (6 off)	0.05	10.925	0.546
Internal door jambs	0.058	21.326	1.237
Paint	60	0.096	5.760
FLOOR FINISHES			
Carpet	61	0.683	41.663
Ceramic tiles	9	0.293	2.637
Skirtings	0.08	30.35	2.428
CEILING FINISHES			
Plasterboard ceiling	97	0.207	20.079
Paint (3 coats)	291	0.096	27.936
		TOTAL	**758**

Kingston Timber floor - Process based energy intensity

	Quantity	Energy Intensity/Unit	Total Energy Intensity GJ
SUBSTRUCTURE			
Prelims			
Fill (screenings)	4	0.691	2.764
100 thick garage concrete slab (23m2)	2.3	4.004	9.209
Sand	1.2	0.617	0.740
Membrane (0.2mm)	25	0.1028	2.570
Concrete footings and thickenings	8	4.004	32.032
Steel mesh SL72 (2 sheets)	0.08	85.463	6.837
Trench mesh (18 sheets, INCS T& B))	0.4	85.463	34.185
N12 bars to piers	0.0018	85.463	0.154
450 dia concrete piers (45m)	7.2	4.004	28.829
Sub-floor wall (assume 600mm high)	21.48	0.56	12.029
Mortar (about 6% of of brickwork m2)			0.720
230 x 230 piers	2.5	0.56	1.400
Timber framed floor and flooring	1.29	21.326	27.511
Bearers (0.55 m3) Joists (0.74 m3)			
Particleboard flooring (82m2)	1.56	30.35	47.346
Paint (3 coats) sub floor walls	90	0.096	8.640
Paint external walls	249	0.096	23.904
ROOF			
Timber truss	1.8	10.925	19.665
steel fixings 22 x1.314kg (per truss)	0.03	85.463	2.564
Colorbond cladding	130	0.588	76.440
Insulation (R3.5 glass fibre)	97	0.3	29.100
Sisalation	130	0.137	17.810
Fascia (49 lm)	9.8	0.588	5.762
Ridge flashing (65 lm)	16.25	0.588	9.555
Gutters (49 lm)	13	0.588	7.644
Downpipes	10	0.266	2.660
Fibrecement eaves lining	23	0.235	5.405
Paint fibrecement sheet (3 coats)	69	0.096	6.624
Soffit framing	0.08	10.925	0.874
EXTERNAL WALLS			
90mm block wall	83	0.56	46.480
Mortar (about 6% of brickwork)			2.780
0.05kg of wall ties per m2 (83 x 0.05)	0.00415	85.463	0.355
Stud frame (cost incl. ins and sis)	1.24	10.925	13.547
Lintels	0.09	21.326	1.919
Nails for framing (6kg/per m3 of timber)	0.008	85.463	0.684
Insulation (R 1.5 fibre glass)	83	0.13	10.790
Building wrap	83	0.137	11.371
Render (total for house)	177		0.000
Plasterboard	83	0.207	17.181
WINDOWS AND DOORS			
Frames	0.108	252.605	27.281
Single glazed (4mm)	27.38	2.44	66.807
Timber entry door (with sidelight)	0.0075	21.326	0.160
Paint entry door	10	0.096	0.960
Garage door (1 off)			3.969
INTERNAL WALLS			
Stud frame internal	0.9	21.326	19.193
Nails for framing (6kg/m3 of timber)	0.0054	85.463	0.462
Plasterboard (68 x 2 check)	136	0.207	28.152
Paint (68 x 2)	408	0.096	39.168
INTERNAL DOORS			
Timber hollow core doors (6 off)	0.05	10.925	0.546
Internal door jambs	0.058	21.326	1.237
Paint	60	0.096	5.760
FLOOR FINISHES			0.000
Carpet and underlay	61	0.683	41.663
Ceramic tiles	9	0.293	2.637
Skirtings (61 lm)	0.08	30.35	2.428
CEILING FINISHES			
Plasterboard ceiling	97	0.207	20.079
Paint	291	0.096	27.936
		TOTAL	**813**

Crimson house (Slab-on-Ground) - Process based energy intensity

	QUANTITY	ENERGY INTENSITY (GJ)	TOTAL ENERGY INTENSITY (GJ)
SUBSTRUCTURE			
(Based on Kingston m2)	183	1.776	325.008
ROOF			
(Energy intensity of truss, fixings and battens based on kingston m2)	210	0.255	53.550
Colorbond roofing	210	0.588	123.480
Ridge flashing (79 lm)	19.75	0.588	11.613
Fascia/barge flashing (68 l/m)	13.6	0.588	7.997
Insulation (R3.5 glass fibre)	188	0.3	56.400
Sisalation	210	0.137	28.770
Gutters (68 lm)	18.02	0.588	10.596
PVC Downpipes (28 l/m)	28	0.266	7.448
eaves lining (27m2)	27	0.288	7.776
Paint (3 coats)	81	0.096	7.776
eaves lining framing	0.11	10.925	1.202
EXTERNAL WALLS			
90mm blockwall	94	0.56	52.640
Mortar (about 6% of ee of brickwork)			3.160
0.05kg of wall ties per m2 (94 x 0.05)	0.0047	85.463	0.402
6kg nails per m3 of timber	0.013	85.463	1.111
Window sills (l/m)	24		
Stud frame 94m2	2.14	10.925	23.380
Lintels	0.26	21.326	5.545
Insulation (R1.5)	94	0.13	12.220
Building wrap	94	0.137	12.878
Plasterboard (94m2)	94	0.207	19.458
Paint plasteboard (94 x 3)	282	0.096	27.072
WINDOWS AND DOORS			
Single glazed aluminium (38m2 @$290m2)	0.175	252.605	44.206
single glazed	38	2.44	92.720
Timber entry door (2 off) (0.015m3)	0.015	21.326	0.320
Garage door (2 off)	17	0.588	9.996
Paint entry doors	20.07	0.096	1.927
INTERNAL WALLS			0.000
Stud wall 128m2	1.93	10.925	21.085
0.05kg of wall ties per m2 (128 x 0.05)	0.0064	85.463	0.547
6kg nails per m3 of timber	0.012	85.463	1.026
Plasterboard 256m2	256	0.207	52.992
Paint 3 coats	768	0.096	73.728
INTERNAL DOORS			
Timber hollow core doors (8 off)	0.067	10.925	0.732
Internal door jambs (based on Kingston)	0.08	21.326	1.706
Paint	80.294	0.096	7.708
FLOOR FINISHES			
Carpet (64m2)	64	0.683	43.712
Floating timber floor (43m2)	0.516	21.326	11.004
Ceramic tiles (15m2)	15	0.293	4.395
Skirtings (107 l/m)	0.08	30.35	2.428
CEILING FINISHES			
Plasterboard ceiling (183 m2)	183	0.207	37.881
Paint (3 coats)	549	0.096	52.704
		TOTAL	**1257**

Crimson house (timber floor) - Process based energy intensity

	QUANTITY	ENERGY INTENSITY/UNIT (GJ)	TOTAL ENERGY INTENSITY (GJ)
SUBSTRUCTURE			
Substructure based on Kingston m2	145	2.02	292.900
Garage slab (33.39M2)	3.339	4.004	13.369
Mesh to garage slab (3 sheets)	0.12	85.463	10.256
Sub floor brickwork (600 high)	31	0.56	17.360
Mortar to brickwork (approx 6% of brickwork)			1.040
ROOF			
Timber truss (includes sis and insulation, battens)			
EE of truss, fixings and battens based on kingston	210	0.255	53.550
Colorbond roofing	210	0.588	123.480
Ridge flashing (79 lm)	19.75	0.588	11.613
Fascia/barge flashing (68 l/m)	13.6	0.588	7.997
Insulation (R3.5 glass fibre)	188	0.3	56.400
Sisalation	210	0.137	28.770
Gutters (68 lm)	18.02	0.588	10.596
PVC Downpipes (28 l/m)	28	0.266	7.448
eaves lining (27m2)	27	0.288	7.776
Paint (3 coats)	81	0.096	7.776
eaves lining framing	0.11	10.925	1.202
EXTERNAL WALLS			
90mm blockwall	94	0.56	52.640
Mortar (about 6% of ee of brickwork)			3.160
0.05kg of wall ties per m2 (94 x 0.05)	0.0047	85.463	0.402
Stud frame 94m2 (volume incls lintels)	2.14	10.925	23.380
Lintels	0.26	21.326	5.545
6kg nails per m3 of timber	0.013	85.463	1.111
Insulation (R1.5)	94	0.13	12.220
Building wrap	94	0.137	12.878
Plasterboard (94m2)	94	0.207	19.458
Paint plasteboard (94 x 3)	282	0.096	27.072
WINDOWS AND DOORS			
Single glazed aluminium (38m2 @$290m2)	0.175	252.605	44.206
single glazed	38	2.44	92.720
Timber entry door (2 off) (0.015m3)	0.015	21.326	0.320
Garage door (2 off)	17	0.588	9.996
Paint entry doors	20.07	0.096	1.927
INTERNAL WALLS			
Stud wall 128m2	1.93	10.925	21.085
0.05kg of wall ties per m2 (128 x 0.05)	0.0064	85.463	0.547
6kg nails per m3 of timber	0.012	85.463	1.026
Plasterboard 256m2	256	0.207	52.992
Paint 3 coats	768	0.096	73.728
INTERNAL DOORS			
Timber hollow core doors (8 off)	0.067	10.925	0.732
Internal door jambs (based on Kingston)	0.08	21.326	1.706
Paint	80.294	0.096	7.708
FLOOR FINISHES			
Carpet (64m2)	64	0.683	43.712
Floating timber floor (43m2)	0.516	21.326	11.004
Ceramic tiles (15m2)	15	0.293	4.395
Skirtings (107 l/m)	0.08	30.35	2.428
CEILING FINISHES			
Plasterboard ceiling (183 m2)	183	0.207	37.881
Paint (3 coats)	549	0.096	52.704
		TOTAL	**1267**

Hickman (Slab-on-Ground) - Process based energy intensity

	QUANTITY	ENERGY INTENSITY/UNIT	TOTAL ENERGY INTENSITY (GJ)
SUBSTRUCTURE			
Based on Kingston m2	140	1.776	248.640
ROOF			
Energy intensity of truss, fixings and battens based on Kingston	170	0.255	43.350
Soffit framing (m2)	26		
Colorbond roofing (including insulation)	170	0.588	99.960
Fascia/barge flashing (57 l/m)	11.4	0.588	6.703
Ridge flashing (20m)	5	0.588	2.940
Insulation (R3.5 glass fibre)	140	0.3	42.000
Sisalation	170	0.137	23.290
Gutters (57 lm)	15	0.588	8.820
PVC Downpipes (18l/m)	18	0.266	4.788
eaves lining (55m2)	26	0.288	7.488
Paint (3 coats)	78	0.096	7.488
eaves lining framing	0.09	10.925	0.983
EXTERNAL WALLS			
90mm block wall	95	0.56	53.200
Mortar (6% EI of brickwork)			3.192
Brick ties (0.05kg ties per m2)	0.00475	85.463	0.406
Stud frame 95 (cost incl. ins 1.5 and sis)	1.418	10.925	15.492
6kg nails per m3 of timber	0.008	85.463	0.684
Lintels	0.3	21.326	6.398
Insulation (R1.5 fibreglass)	95	0.13	12.350
Building wrap	95	0.137	13.015
Plasterboard (95m2)	95	0.207	19.665
Paint plasteboard (95 x 3)	285	0.096	27.360
WINDOWS AND DOORS			
Single glazed aluminium (34m2 @$290m2)	0.203	252.605	51.279
single glazed	34	2.44	82.960
Timber entry door (2 off)	0.015	21.326	0.320
Garage door (2 off)	17	0.588	9.996
INTERNAL WALLS			0.000
Stud wall 104m2	1.01	10.925	11.034
Plasterboard 208m2	208	0.207	43.056
6kg nails per m3 of timber	0.006	85.463	0.513
Paint 3 coats (208 x 3)	624	0.096	59.904
INTERNAL DOORS			0.000
Cavity sliders and hollow core doors (10 off)	0.084	10.925	0.918
Door jambs	0.1	21.326	2.133
Paint (3 coats)	100	0.096	9.600
FLOOR FINISHES			0.000
Carpet (52m2)	52	0.683	35.516
Ceramic tiles (15m2)	15	0.293	4.395
Skirtings (110 l/m)	0.08	30.35	2.428
CEILING FINISHES			0.000
Plasterboard ceiling (144 m2)	144	0.207	29.808
Paint (3 coats)	432	0.096	41.472
		TOTAL	**937**

Hickman (Timber-floor) - Process based energy intensity

	QUANTITY	ENERGY INTENSITY/UNIT	TOTAL ENERGY INTENSITY (GJ)
SUBSTRUCTURE			
Energy Intensity of substructure based on Kingston m2	140	2.02	282.800
Sub floor walls (600mm high)	32.4	0.56	18.144
Mortar (sub-floor walls, 6% EI of brickwork)			1.090
Paint to sub-floor walls (3 coats)	97.2	0.096	9.331
ROOF			
EE of truss, fixings and battens based on Kingston	170	0.255	43.350
Soffit framing (m2)	26		
Colorbond roofing (including insulation)	170	0.588	99.960
Fascia/barge flashing (57 l/m)	11.4	0.588	6.703
Ridge flashing (20m)	5	0.588	2.940
Insulation (R3.5 glass fibre)	140	0.3	42.000
Sisalation	170	0.137	23.290
Gutters (57 lm)	15	0.588	8.820
PVC Downpipes (18l/m)	18	0.266	4.788
eaves lining (55m2)	26	0.288	7.488
Paint (3 coats)	78	0.096	7.488
eaves lining framing	0.09	10.925	0.983
EXTERNAL WALLS			0.000
90mm block wall	95	0.56	53.200
Mortar (6% EI of brickwork)			3.192
Brick ties (0.05kg ties per m2)	0.00475	85.463	0.406
6kg nails per m3 timber	0.008	85.463	0.684
Stud frame 95 (cost incl. ins 1.5 and sis)	1.418	10.925	15.492
Lintels	0.3	21.326	6.398
Insulation (R1.5 fibreglass)	95	0.13	12.350
Building wrap	95	0.137	13.015
Plasterboard (95m2)	95	0.207	19.665
Paint plasteboard (95 x 3)	285	0.096	27.360
WINDOWS AND DOORS			0.000
Single glazed aluminium (34m2 @$290m2)	0.203	252.605	51.279
single glazed	34	2.44	82.960
Timber entry door (2 off)	0.015	21.326	0.320
Garage door (2 off)	17	0.588	9.996
INTERNAL WALLS			0.000
Stud wall 104m2	1.01	10.925	11.034
6kg nails per m3 timber	0.006	85.463	0.513
Plasterboard 208m2	208	0.207	43.056
Paint 3 coats (208 x 3)	624	0.096	59.904
INTERNAL DOORS			
Cavity sliders and hollow core doors (10 off)	0.084	10.925	0.918
Door jambs	0.1	21.326	2.133
Paint (3 coats)	100	0.096	9.600
FLOOR FINISHES			
Carpet (52m2)	52	0.683	35.516
Ceramic tiles (15m2)	15	0.293	4.395
Skirtings (110 l/m)	0.08	30.35	2.428
CEILING FINISHES			
Plasterboard ceiling (144 m2)	144	0.207	29.808
Paint (3 coats)	432	0.096	41.472
		TOTAL	**1000**

APPENDIX D – RESULTING EMBODIED ENERGY (IOBHA) FROM THERMAL PERFORMANCE IMPROVEMENTS

The following calculations show resulting construction cost and house's total energy from thermal performance improvements. The resulting IOBHA embodied energy is highlighted in blue.

Kingston 5-6 star

Design 1

Pure INPUT-OUTPUT TEI	1610.97	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	151,510	
PBHA	763	GJ/unit						
IOBHA	**1544.16**	**GJ/unit**						
	781.16	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	52.8699			52.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	781.1608			**781.2**	GJ/unit			

Design 2

Pure INPUT-OUTPUT TEI	1585.96	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	149,158	
PBHA	737	GJ/unit						
IOBHA	**1506.03**	**GJ/unit**						
	769.03	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	52.0492			52.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	769.0342			**769.0**	GJ/unit			

Design 3

Pure INPUT-OUTPUT TEI	1611.12	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	151,524	
PBHA	839	GJ/unit						
IOBHA	**1620.23**	**GJ/unit**						
	781.23	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	52.8748			52.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	781.2329			**781.2**	GJ/unit			

Design 4

Pure INPUT-OUTPUT TEI	1593.16	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	149,835	
PBHA	812	GJ/unit						
IOBHA	**1584.52**	**GJ/unit**						
	772.52	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	52.2854			52.3	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	772.5247			**772.5**	GJ/unit			

Design 5

Pure INPUT-OUTPUT TEI	1615.69	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	151,954	
PBHA	842	GJ/unit						
IOBHA	**1625.45**	**GJ/unit**						
	783.45	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	53.0248			53.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	783.4499			**783.4**	GJ/unit			

Design 6

Pure INPUT-OUTPUT TEI	1590.20	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	149,557	
PBHA	751	GJ/unit						
IOBHA	**1522.09**	**GJ/unit**						
	771.09	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	52.1884			52.2	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	771.0914			**771.1**	GJ/unit			

Design 7

Pure INPUT-OUTPUT TEI	1628.58	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	153,166	
PBHA	849	GJ/unit						
IOBHA	**1638.70**	**GJ/unit**						
	789.70	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	53.4478			53.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	789.6988			**789.7**	GJ/unit			

Design 8

Pure INPUT-OUTPUT TEI	1712.87	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,094	
PBHA	1023	GJ/unit						
IOBHA	**1853.57**	**GJ/unit**						
	830.57	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.2143			56.2	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	830.5743			**830.6**	GJ/unit			

Design 9

Pure INPUT-OUTPUT TEI	1662.56	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	156,362	
PBHA	862	GJ/unit						
IOBHA	**1668.18**	**GJ/unit**						
	806.18	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	54.5630			54.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	806.1769			**806.2**	GJ/unit			

Design 10

Pure INPUT-OUTPUT TEI	1759.86	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	165,513	
PBHA	1291	GJ/unit						
IOBHA	**2144.36**	**GJ/unit**						
	853.36	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	57.7563			57.8	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	853.3579			**853.4**	GJ/unit			

Design 11

Pure INPUT-OUTPUT TEI	1601.73	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	150,641	
PBHA	781	GJ/unit						
IOBHA	**1557.68**	**GJ/unit**						
	776.68	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	52.5667			52.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	776.6803			**776.7**	GJ/unit			

Design 12

Pure INPUT-OUTPUT TEI	1633.87	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	153,664	
PBHA	800	GJ/unit						
IOBHA	**1592.27**	**GJ/unit**						
	792.27	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	53.6216			53.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	792.2664			**792.3**	GJ/unit			

Design 13

Pure INPUT-OUTPUT TEI	1674.07	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	157,445	
PBHA	893	GJ/unit						
IOBHA	**1704.76**	**GJ/unit**						
	811.76	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	54.9409			54.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	811.7606			**811.8**	GJ/unit			

Design 14

Pure INPUT-OUTPUT TEI	1636.07	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	153,871	
PBHA	835	GJ/unit						
IOBHA	**1628.33**	**GJ/unit**						
	793.33	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	53.6938			53.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	793.3337			**793.3**	GJ/unit			

Design 15

Pure INPUT-OUTPUT TEI	1677.82	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	157,797	
PBHA	857	GJ/unit						
IOBHA	**1670.58**	**GJ/unit**						
	813.58	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	55.0638			55.1	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	813.5755			**813.6**	GJ/unit			

Design 16

Pure INPUT-OUTPUT TEI	1707.26	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	160,566	
PBHA	1066	GJ/unit						
IOBHA	**1893.85**	**GJ/unit**						
	827.85	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.0300			56.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	827.8520			**827.9**	GJ/unit			

Kingston 6-7 star

Design 1

Pure INPUT-OUTPUT TEI	1658.77	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	156,006	
PBHA	930	GJ/unit						
IOBHA	**1734.34**	**GJ/unit**						
	804.34	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	54.4388			54.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	804.3414			**804.3**	GJ/unit			

Design 2

Pure INPUT-OUTPUT TEI	1714.78	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,273	
PBHA	972	GJ/unit						
IOBHA	**1803.50**	**GJ/unit**						
	831.50	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.2767			56.3	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	831.4972			**831.5**	GJ/unit			

Design 3

Pure INPUT-OUTPUT TEI	1698.02	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	159,697	
PBHA	904	GJ/unit						
IOBHA	**1727.37**	**GJ/unit**						
	823.37	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	55.7268			55.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	823.3716			**823.4**	GJ/unit			

Design 4

Pure INPUT-OUTPUT TEI	1667.19	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	156,798	
PBHA	938	GJ/unit						
IOBHA	**1746.42**	**GJ/unit**						
	808.42	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	54.7152			54.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	808.4248			**808.4**	GJ/unit			

Design 5

Pure INPUT-OUTPUT TEI	1645.33	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	154,742	
PBHA	824	GJ/unit						
IOBHA	**1621.82**	**GJ/unit**						
	797.82	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	53.9977			54.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	797.8244			**797.8**	GJ/unit			

Design 6

Pure INPUT-OUTPUT TEI	1649.86	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	155,168	
PBHA	833	GJ/unit						
IOBHA	**1633.02**	**GJ/unit**						
	800.02	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	54.1464			54.1	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	800.0208			**800.0**	GJ/unit			

Design 7

Pure INPUT-OUTPUT TEI	1686.13	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	158,579	
PBHA	988	GJ/unit						
IOBHA	**1805.61**	**GJ/unit**						
	817.61	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	55.3367			55.3	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	817.6074			**817.6**	GJ/unit			

Design 8

Pure INPUT-OUTPUT TEI	1704.90	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	160,344	
PBHA	955	GJ/unit						
IOBHA	**1781.71**	**GJ/unit**						
	826.71	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	55.9526			56.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	826.7074			**826.7**	GJ/unit			

Design 9

Pure INPUT-OUTPUT TEI	1710.39	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	160,861	
PBHA	924	GJ/unit						
IOBHA	**1753.37**	**GJ/unit**						
	829.37	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.1330			56.1	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	829.3730			**829.4**	GJ/unit			

Design 10

Pure INPUT-OUTPUT TEI	1718.88	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,659	
PBHA	932	GJ/unit						
IOBHA	**1765.49**	**GJ/unit**						
	833.49	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.4114			56.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	833.4873			**833.5**	GJ/unit			

De sign 11

Pure INPUT-OUTPUT TEI	1714.56	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,253	
PBHA	932	GJ/unit						
IOBHA	**1763.39**	**GJ/unit**						
	831.39	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.2698			56.3	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	831.3941			**831.4**	GJ/unit			

Design 12

Pure INPUT-OUTPUT TEI	1752.76	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	164,845	
PBHA	1103	GJ/unit						
IOBHA	**1952.91**	**GJ/unit**						
	849.91	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	57.5232			57.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	849.9138			**849.9**	GJ/unit			

Design 13

Pure INPUT-OUTPUT TEI	1748.05	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	164,402	
PBHA	1016	GJ/unit						
IOBHA	**1863.63**	**GJ/unit**						
	847.63	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	57.3686			57.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	847.6298			**847.6**	GJ/unit			

Design 14

Pure INPUT-OUTPUT TEI	1719.61	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,728	
PBHA	857	GJ/unit						
IOBHA	**1690.84**	**GJ/unit**						
	833.84	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.4355			56.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	833.8431			**833.8**	GJ/unit			

Design 15

Pure INPUT-OUTPUT TEI	1728.73	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	162,585	
PBHA	879	GJ/unit						
IOBHA	**1717.26**	**GJ/unit**						
	838.26	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.7346			56.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	838.2616			**838.3**	GJ/unit			

Design 16

Pure INPUT-OUTPUT TEI	1758.06	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	165,344	
PBHA	1112	GJ/unit						
IOBHA	**1964.49**	**GJ/unit**						
	852.49	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	57.6973			57.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	852.4866			**852.5**	GJ/unit			

Design 17

Pure INPUT-OUTPUT TEI	1736.15	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	163,283	
PBHA	922	GJ/unit						
IOBHA	**1763.86**	**GJ/unit**						
	841.86	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	56.9781			57.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	841.8604			**841.9**	GJ/unit			

Design 18

Pure INPUT-OUTPUT TEI	1718.90	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,661	
PBHA	909	GJ/unit						
IOBHA	**1742.50**	**GJ/unit**						
	833.50	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	56.4121			56.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	833.4976			**833.5**	GJ/unit			

Design 19

Pure INPUT-OUTPUT TEI	1726.40	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	162,366	
PBHA	957	GJ/unit						
IOBHA	**1794.13**	**GJ/unit**						
	837.13	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	56.6581			56.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	837.1325			**837.1**	GJ/unit			

Design 20

Pure INPUT-OUTPUT TEI	1757.87	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	165,326	
PBHA	1026	GJ/unit						
IOBHA	**1878.39**	**GJ/unit**						
	852.39	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	57.6910			57.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	852.3938			**852.4**	GJ/unit			

Design 21

Pure INPUT-OUTPUT TEI	1752.34	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	164,806	
PBHA	1224	GJ/unit						
IOBHA	**2073.71**	**GJ/unit**						
	849.71	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	57.5096			57.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	849.7127			**849.7**	GJ/unit			

Design 22

Pure INPUT-OUTPUT TEI	1704.41	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	160,298	
PBHA	956	GJ/unit						
IOBHA	**1782.47**	**GJ/unit**						
	826.47	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	55.9365			55.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	826.4702			**826.5**	GJ/unit			

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Design 1

Pure INPUT-OUTPUT TEI	1812.68	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	170,481	
PBHA	978	GJ/unit						
IOBHA	**1856.97**	**GJ/unit**						
	878.97	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	59.4899			59.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	878.9721			**879.0**	GJ/unit			

Design 2

Pure INPUT-OUTPUT TEI	1776.13	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	167,043	
PBHA	931	GJ/unit						
IOBHA	**1792.25**	**GJ/unit**						
	861.25	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	58.2902			58.3	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	861.2464			**861.2**	GJ/unit			

Design 3

Pure INPUT-OUTPUT TEI	1763.01	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	165,809	
PBHA	940	GJ/unit						
IOBHA	**1794.88**	**GJ/unit**						
	854.88	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	57.8596			57.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	854.8841			**854.9**	GJ/unit			

Design 4

Pure INPUT-OUTPUT TEI	1802.60	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	169,533	
PBHA	974	GJ/unit						
IOBHA	**1848.08**	**GJ/unit**						
	874.08	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	59.1591			59.2	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	874.0844			**874.1**	GJ/unit			

Design 5

Pure INPUT-OUTPUT TEI	1798.18	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	169,117	
PBHA	1330	GJ/unit						
IOBHA	**2201.94**	**GJ/unit**						
	871.94	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	59.0139			59.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	871.9396			**871.9**	GJ/unit			

Design 6

Pure INPUT-OUTPUT TEI	1794.48	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	168,769	
PBHA	953	GJ/unit						
IOBHA	**1823.15**	**GJ/unit**						
	870.15	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	58.8925			58.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	870.1453			**870.1**	GJ/unit			

Design 7

Pure INPUT-OUTPUT TEI	1752.20	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	164,793	
PBHA	982	GJ/unit						
IOBHA	**1831.65**	**GJ/unit**						
	849.65	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	57.5051			57.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	849.6457			**849.6**	GJ/unit			

Design 8

Pure INPUT-OUTPUT TEI	1778.67	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	167,282
PBHA	1145	GJ/unit					
IOBHA	**2007.48**	**GJ/unit**					
	862.48	diff (unmodified pathways)					
	residential	building		total (unit)			
direct energy	58.3736			58.4	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	862.4786			**862.5**	GJ/unit		

Design 9

Pure INPUT-OUTPUT TEI	1762.37	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	165,749
PBHA	1078	GJ/unit					
IOBHA	**1932.57**	**GJ/unit**					
	854.57	diff (unmodified pathways)					
	residential	building		total (unit)			
direct energy	57.8387			57.8	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	854.5747			**854.6**	GJ/unit		

Design 10

Pure INPUT-OUTPUT TEI	1771.70	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	166,627
PBHA	1124	GJ/unit					
IOBHA	**1983.10**	**GJ/unit**					
	859.10	diff (unmodified pathways)					
	residential	building		total (unit)			
direct energy	58.1450			58.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	859.1015			**859.1**	GJ/unit		

Design 11

Pure INPUT-OUTPUT TEI	1856.79	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	174,629	
PBHA	1072	GJ/unit						
IOBHA	**1953.00**	**GJ/unit**						
	881.00	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	60.9374			60.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	900.3585			**900.4**	GJ/unit			

Design 12

Pure INPUT-OUTPUT TEI	1722.48	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,998	
PBHA	873	GJ/unit						
IOBHA	**1708.24**	**GJ/unit**						
	835.24	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	56.5297			56.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	835.2352			**835.2**	GJ/unit			

Design 13

Pure INPUT-OUTPUT TEI	1787.35	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	168,099	
PBHA	956	GJ/unit						
IOBHA	**1815.00**	**GJ/unit**						
	859.00	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	58.6587			58.7	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	866.6909			**866.7**	GJ/unit			

Design 14

Pure INPUT-OUTPUT TEI	1732.05	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	162,898	
PBHA	873	GJ/unit						
IOBHA	**1712.88**	**GJ/unit**						
	839.88	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	56.8438			56.8	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	839.8754			**839.9**	GJ/unit			

Design 15

Pure INPUT-OUTPUT TEI	1900.94	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	178,782	
PBHA	1134	GJ/unit						
IOBHA	**2055.77**	**GJ/unit**						
	921.77	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	62.3866			62.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	921.7707			**921.8**	GJ/unit			

Design 16

Pure INPUT-OUTPUT TEI	1753.11	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	164,878	
PBHA	895	GJ/unit						
IOBHA	**1745.08**	**GJ/unit**						
	850.08	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	57.5347			57.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	850.0840			**850.1**	GJ/unit			

Design 17

Pure INPUT-OUTPUT TEI	1721.28	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	161,885	
PBHA	963	GJ/unit						
IOBHA	**1797.65**	**GJ/unit**						
	834.65	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	56.4903			56.5	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	834.6526			**834.7**	GJ/unit			

Design 18

Pure INPUT-OUTPUT TEI	1833.20	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	172,411	
PBHA	1120	GJ/unit						
IOBHA	**2008.92**	**GJ/unit**						
	888.92	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	60.1634			60.2	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	888.9229			**888.9**	GJ/unit			

Design 19

Pure INPUT-OUTPUT TEI	1894.62	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	178,187	
PBHA	918	GJ/unit						
IOBHA	**1836.70**	**GJ/unit**						
	918.70	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	62.1789			62.2	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	918.7030			**918.7**	GJ/unit			

Design 20

Pure INPUT-OUTPUT TEI	1902.38	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	178,917	
PBHA	940	GJ/unit						
IOBHA	**1862.47**	**GJ/unit**						
	922.47	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	62.4337			62.4	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	922.4668			**922.5**	GJ/unit			

Design 21

Pure INPUT-OUTPUT TEI	1884.05	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	177,193	
PBHA	949	GJ/unit						
IOBHA	**1862.58**	**GJ/unit**						
	913.58	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	61.8321			61.8	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	913.5781			**913.6**	GJ/unit			

Design 22

Pure INPUT-OUTPUT TEI	1798.18	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	169,117	
PBHA	1325	GJ/unit						
IOBHA	**2196.94**	**GJ/unit**						
	871.94	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	59.0139			59.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	871.9396			**871.9**	GJ/unit			

Design 23

Pure INPUT-OUTPUT TEI	1858.52	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	174,792	
PBHA	1027	GJ/unit						
IOBHA	**1928.20**	**GJ/unit**						
	901.20	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	60.9942			61.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	901.1989			**901.2**	GJ/unit			

Design 24

Pure INPUT-OUTPUT TEI	1785.25	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	167,901	
PBHA	956	GJ/unit						
IOBHA	**1821.67**	**GJ/unit**						
	865.67	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	58.5896			58.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	865.6701			**865.7**	GJ/unit			

Design 25

Pure INPUT-OUTPUT TEI	1857.02	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	174,651	
PBHA	1114	GJ/unit						
IOBHA	**2014.47**	**GJ/unit**						
	900.47	diff (unmodified pathways)						
	residential	building		total (unit)				
direct energy	60.9450			60.9	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	900.4720			**900.5**	GJ/unit			

Design 26

Pure INPUT-OUTPUT TEI	1950.80	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	183,471	
PBHA	1370	GJ/unit						
IOBHA	**2315.95**	**GJ/unit**						
	945.95	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	64.0228			64.0	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	945.9464			**945.9**	GJ/unit			

Design 27

Pure INPUT-OUTPUT TEI	1908.58	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	179,500	
PBHA	1119	GJ/unit						
IOBHA	**2044.47**	**GJ/unit**						
	925.47	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	62.6371			62.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	925.4726			**925.5**	GJ/unit			

Design 28

Pure INPUT-OUTPUT TEI	1997.55	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	Construction cost $	
PA		GJ/unit		residential	10.6327	0.3490	187,868	
PBHA	1119	GJ/unit						
IOBHA	**2087.62**	**GJ/unit**						
	968.62	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	65.5571			65.6	GJ/unit			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	968.6166			**968.6**	GJ/unit			

Crimson 5-6 star

Design 1

Pure INPUT-OUTPUT TEI	2690.97	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	253,083
PBHA	1602	GJ/unit					
IOBHA	**2906.85**	**GJ/unit**					
	1304.85	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.3141			88.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1304.8545			**1304.9**	GJ/unit		

Design 2

Pure INPUT-OUTPUT TEI	2588.10	GJ/unit		sector	TEI (GJ/$100	DEI (GJ/$100 **0)**	Construction cost $
PA		GJ/unit		residential buildi	10.6327	0.3490	243,408
PBHA	1379	GJ/unit					
IOBHA	**2633.97**	**GJ/unit**					
	1254.97	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	84.9380			84.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1254.9718			**1255.0**	GJ/unit		

Design 3

Pure INPUT-OUTPUT TEI	2618.60	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	246,277
PBHA	1394	GJ/unit					
IOBHA	**2663.76**	**GJ/unit**					
	1269.76	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	85.9392			85.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1269.7639			**1269.8**	GJ/unit		

Design 4

Pure INPUT-OUTPUT TEI	2588.60	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	243,455
PBHA	1310	GJ/unit					
IOBHA	**2565.21**	**GJ/unit**					
	1255.21	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	84.9544			85.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1255.2141			**1255.2**	GJ/unit		

Design 5

Pure INPUT-OUTPUT TEI	2580.61	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	242,704
PBHA	1374	GJ/unit					
IOBHA	**2625.34**	**GJ/unit**					
	1251.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	84.6924			84.7	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1251.3421			**1251.3**	GJ/unit		

Design 6

Pure INPUT-OUTPUT TEI	2525.58	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	237,528
PBHA	1239	GJ/unit					
IOBHA	**2463.66**	**GJ/unit**					
	1224.66	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	82.8862			82.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1224.6555			**1224.7**	GJ/unit		

Design 7

Pure INPUT-OUTPUT TEI	2553.85	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	240,187
PBHA	1286	GJ/unit					
IOBHA	**2524.36**	**GJ/unit**					
	1238.36	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	83.8140			83.8	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1238.3648			**1238.4**	GJ/unit		

Design 8

Pure INPUT-OUTPUT TEI	2628.74	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	247,231
PBHA	1291	GJ/unit					
IOBHA	**2565.68**	**GJ/unit**					
	1274.68	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.2721			86.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1274.6826			**1274.7**	GJ/unit		

Design 9

Pure INPUT-OUTPUT TEI	2625.16	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	246,894
PBHA	1418	GJ/unit					
IOBHA	**2690.95**	**GJ/unit**					
	1272.95	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.1545			86.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1272.9450			**1272.9**	GJ/unit		

Design 10

Pure INPUT-OUTPUT TEI	2684.90	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	252,512
PBHA	1601	GJ/unit					
IOBHA	**2902.91**	**GJ/unit**					
	1301.91	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.1149			88.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1301.9105			**1301.9**	GJ/unit		

Design 11

Pure INPUT-OUTPUT TEI	2644.58	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	248,720
PBHA	1435	GJ/unit					
IOBHA	**2717.36**	**GJ/unit**					
	1282.36	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.7917			86.8	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1282.3596			**1282.4**	GJ/unit		

Design 12

Pure INPUT-OUTPUT TEI	2670.71	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	251,178
PBHA	1383	GJ/unit					
IOBHA	**2678.03**	**GJ/unit**					
	1295.03	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	87.6494			87.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1295.0326			**1295.0**	GJ/unit		

Crimson 6-7 stars

Design 1

Pure INPUT-OUTPUT TEI	2676.91	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	251,761
PBHA	1501	GJ/unit					
IOBHA	**2799.04**	**GJ/unit**					
	1298.04	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	87.8528			87.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1298.0385			**1298.0**	GJ/unit		

Design 2

Pure INPUT-OUTPUT TEI	2605.27	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	245,023
PBHA	1343	GJ/unit					
IOBHA	**2606.30**	**GJ/unit**					
	1263.30	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	85.5016			85.5	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1263.2985			**1263.3**	GJ/unit		

Design 3

Pure INPUT-OUTPUT TEI	2635.28	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	247,846
PBHA	1426	GJ/unit					
IOBHA	**2703.85**	**GJ/unit**					
	1277.85	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.4867			86.5	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1277.8534			**1277.9**	GJ/unit		

Design 4

Pure INPUT-OUTPUT TEI	2672.90	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	251,384
PBHA	1397	GJ/unit					
IOBHA	**2693.09**	**GJ/unit**					
	1296.09	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	87.7213			87.7	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1296.0947			**1296.1**	GJ/unit		

Design 5

Pure INPUT-OUTPUT TEI	2624.68	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	246,849
PBHA	1360	GJ/unit					
IOBHA	**2632.71**	**GJ/unit**					
	1272.71	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.1388			86.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1272.7130			**1272.7**	GJ/unit		

Design 6

Pure INPUT-OUTPUT TEI	2684.11	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	252,438
PBHA	1463	GJ/unit					
IOBHA	**2764.53**	**GJ/unit**					
	1301.53	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.0891			88.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1301.5290			**1301.5**	GJ/unit		

Design 7

Pure INPUT-OUTPUT TEI	2684.11	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	252,438
PBHA	1463	GJ/unit					
IOBHA	**2764.53**	**GJ/unit**					
	1301.53	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.0891			88.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1301.5290			**1301.5**	GJ/unit		

Design 8

Pure INPUT-OUTPUT TEI	2729.06	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	256,666
PBHA	1636	GJ/unit					
IOBHA	**2954.00**	**GJ/unit**					
	1318.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.5644			89.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1323.3279			**1323.3**	GJ/unit		

Design 9

Pure INPUT-OUTPUT TEI	2679.45	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	252,000
PBHA	1470	GJ/unit					
IOBHA	**2769.27**	**GJ/unit**					
	1299.27	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	87.9362			87.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1299.2707			**1299.3**	GJ/unit		

Design 10

Pure INPUT-OUTPUT TEI	2634.22	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	247,746
PBHA	1449	GJ/unit					
IOBHA	**2726.34**	**GJ/unit**					
	1277.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	86.4518			86.5	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1277.3378			**1277.3**	GJ/unit		

Design 11

Pure INPUT-OUTPUT TEI	2748.48	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	258,492
PBHA	1653	GJ/unit					
IOBHA	**2985.74**	**GJ/unit**					
	1332.74	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	90.2016			90.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1332.7424			**1332.7**	GJ/unit		

Design 12

Pure INPUT-OUTPUT TEI	2737.70	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	257,478
PBHA	1418	GJ/unit					
IOBHA	**2745.51**	**GJ/unit**					
	1327.51	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.8478			89.8	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1327.5144			**1327.5**	GJ/unit		

Design 13

Pure INPUT-OUTPUT TEI	2686.26	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	252,640
PBHA	1414	GJ/unit					
IOBHA	**2716.57**	**GJ/unit**					
	1302.57	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.1596			88.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1302.5705			**1302.6**	GJ/unit		

Design 14

Pure INPUT-OUTPUT TEI	2698.87	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	253,826
PBHA	1487	GJ/unit					
IOBHA	**2795.69**	**GJ/unit**					
	1308.69	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.5734			88.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1308.6853			**1308.7**	GJ/unit		

Design 15

Pure INPUT-OUTPUT TEI	2698.87	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	253,826
PBHA	1487	GJ/unit					
IOBHA	**2795.69**	**GJ/unit**					
	1308.69	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.5734			88.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1308.6853			**1308.7**	GJ/unit		

Design 16

Pure INPUT-OUTPUT TEI	2802.14	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	263,539
PBHA	1817	GJ/unit					
IOBHA	**3175.76**	**GJ/unit**					
	1358.76	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.9628			92.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1358.7639			**1358.8**	GJ/unit		

Design 17

Pure INPUT-OUTPUT TEI	2728.77	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	256,638
PBHA	1393	GJ/unit					
IOBHA	**2716.18**	**GJ/unit**					
	1323.18	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.5547			89.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1323.1835			**1323.2**	GJ/unit		

Design 18

Pure INPUT-OUTPUT TEI	2756.33	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	259,230
PBHA	1441	GJ/unit					
IOBHA	**2777.55**	**GJ/unit**					
	1336.55	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	90.4592			90.5	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1336.5474			**1336.5**	GJ/unit		

Design 19

Pure INPUT-OUTPUT TEI	2742.55	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	257,934
PBHA	1412	GJ/unit					
IOBHA	**2741.87**	**GJ/unit**					
	1329.87	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	90.0069			90.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1329.8655			**1329.9**	GJ/unit		

Design 20

Pure INPUT-OUTPUT TEI	2832.69	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	266,412
PBHA	1969	GJ/unit					
IOBHA	**3342.58**	**GJ/unit**					
	1373.58	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	92.9653			93.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1373.5766			**1373.6**	GJ/unit		

Design 21

Pure INPUT-OUTPUT TEI	2710.18	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	254,890
PBHA	1521	GJ/unit					
IOBHA	**2835.17**	**GJ/unit**					
	1314.17	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	88.9447			88.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1314.1711			**1314.2**	GJ/unit		

Design 22

Pure INPUT-OUTPUT TEI	2794.37	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	262,808
PBHA	1479	GJ/unit					
IOBHA	**2834.00**	**GJ/unit**					
	1355.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.7077			91.7	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1354.9950			**1355.0**	GJ/unit		

Design 23

Pure INPUT-OUTPUT TEI	2712.95	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	255,150
PBHA	1401	GJ/unit					
IOBHA	**2716.51**	**GJ/unit**					
	1315.51	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.0354			89.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1315.5116			**1315.5**	GJ/unit		

Design 24

Pure INPUT-OUTPUT TEI	2778.55	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,320
PBHA	1490	GJ/unit					
IOBHA	**2837.32**	**GJ/unit**					
	1347.32	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.1885			91.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1347.3231			**1347.3**	GJ/unit		

Crimson 7-8 stars

Design 1

Pure INPUT-OUTPUT TEI	2804.07	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	263,720
PBHA	1482	GJ/unit					
IOBHA	**2841.70**	**GJ/unit**					
	1359.70	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	92.0260			92.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1359.6971			**1359.7**	GJ/unit		

Design 2

Pure INPUT-OUTPUT TEI	2736.09	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	257,327
PBHA	1455	GJ/unit					
IOBHA	**2781.74**	**GJ/unit**					
	1326.74	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.7951			89.8	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1326.7359			**1326.7**	GJ/unit		

Design 3

Pure INPUT-OUTPUT TEI	2778.66	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$1000)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,330
PBHA	1699	GJ/unit					
IOBHA	**3046.37**	**GJ/unit**					
	1347.37	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.1920			91.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1347.3747			**1347.4**	GJ/unit		

Design 4

Pure INPUT-OUTPUT TEI	2778.82	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,345
PBHA	1395	GJ/unit					
IOBHA	**2742.45**	**GJ/unit**					
	1347.45	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.1972			91.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1347.4520			**1347.5**	GJ/unit		

Design 5

Pure INPUT-OUTPUT TEI	2866.01	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	269,546
PBHA	1475	GJ/unit					
IOBHA	**2864.74**	**GJ/unit**					
	1389.74	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	94.0590			94.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1389.7350			**1389.7**	GJ/unit		

Design 6

Pure INPUT-OUTPUT TEI	2898.35	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	272,587
PBHA	1574	GJ/unit					
IOBHA	**2979.41**	**GJ/unit**					
	1405.41	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	95.1201			95.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1405.4139			**1405.4**	GJ/unit		

Design 7

Pure INPUT-OUTPUT TEI	2790.02	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	262,399
PBHA	1885	GJ/unit					
IOBHA	**3237.89**	**GJ/unit**					
	1352.89	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.5650			91.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1352.8863			**1352.9**	GJ/unit		

Design 8

Pure INPUT-OUTPUT TEI	2781.71	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,617
PBHA	1758	GJ/unit					
IOBHA	**3106.85**	**GJ/unit**					
	1348.85	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.2921			91.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1348.8544			**1348.9**	GJ/unit		

Design 9

Pure INPUT-OUTPUT TEI	2879.68	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	270,831
PBHA	1687	GJ/unit					
IOBHA	**3083.36**	**GJ/unit**					
	1396.36	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	94.5074			94.5	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1396.3603			**1396.4**	GJ/unit		

Design 10

Pure INPUT-OUTPUT TEI	2804.07	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	263,720
PBHA	1479	GJ/unit					
IOBHA	**2838.70**	**GJ/unit**					
	1359.70	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	92.0260			92.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1359.6971			**1359.7**	GJ/unit		

Design 12

Pure INPUT-OUTPUT TEI	2867.27	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	269,664
PBHA	1568	GJ/unit					
IOBHA	**2958.34**	**GJ/unit**					
	1390.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	94.1001			94.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1390.3434			**1390.3**	GJ/unit		

Design 13

Pure INPUT-OUTPUT TEI	2885.74	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	271,401
PBHA	1659	GJ/unit					
IOBHA	**3058.30**	**GJ/unit**					
	1399.30	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	94.7063			94.7	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1399.2991			**1399.3**	GJ/unit		

Design 14

Pure INPUT-OUTPUT TEI	2719.88	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	255,802
PBHA	1521	GJ/unit					
IOBHA	**2839.87**	**GJ/unit**					
	1318.87	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	89.2629			89.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1318.8732			**1318.9**	GJ/unit		

Design 15

Pure INPUT-OUTPUT TEI	2778.82	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,345
PBHA	1391	GJ/unit					
IOBHA	**2738.45**	**GJ/unit**					
	1347.45	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.1972			91.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1347.4520			**1347.5**	GJ/unit		

Design 16

Pure INPUT-OUTPUT TEI	2832.69	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	266,412
PBHA	1964	GJ/unit					
IOBHA	**3337.58**	**GJ/unit**					
	1373.58	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	92.9653			93.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1373.5766			**1373.6**	GJ/unit		

Design 17

Pure INPUT-OUTPUT TEI	2977.76	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	280,056
PBHA	1481	GJ/unit					
IOBHA	**2924.92**	**GJ/unit**					
	1443.92	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	97.7265			97.7	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1443.9229			**1443.9**	GJ/unit		

Design 18

Pure INPUT-OUTPUT TEI	2963.98	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	278,760
PBHA	1452	GJ/unit					
IOBHA	**2889.24**	**GJ/unit**					
	1437.24	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	97.2742			97.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1437.2409			**1437.2**	GJ/unit		

Design 19

Pure INPUT-OUTPUT TEI	2784.23	GJ/unit		sector	TEI (GJ/$10)	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	261,854
PBHA	1391	GJ/unit					
IOBHA	**2741.08**	**GJ/unit**					
	1350.08	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	91.3748			91.4	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1350.0763			**1350.1**	GJ/unit		

Design 20

Pure INPUT-OUTPUT TEI	2898.35	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	272,587
PBHA	1573	GJ/unit					
IOBHA	**2978.41**	**GJ/unit**					
	1405.41	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	95.1201			95.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1405.4139			**1405.4**	GJ/unit		

Design 21

Pure INPUT-OUTPUT TEI	2867.27	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	269,664
PBHA	1568	GJ/unit					
IOBHA	**2958.34**	**GJ/unit**					
	1390.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	94.1001			94.1	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1390.3434			**1390.3**	GJ/unit		

Design 22

Pure INPUT-OUTPUT TEI	2921.36	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	274,751
PBHA	1724	GJ/unit					
IOBHA	**3140.57**	**GJ/unit**					
	1416.57	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	95.8753			95.9	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1416.5712			**1416.6**	GJ/unit		

Design 23

Pure INPUT-OUTPUT TEI	3054.13	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	287,238
PBHA	2009	GJ/unit					
IOBHA	**3489.95**	**GJ/unit**					
	1480.95	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	100.2326			100.2	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1480.9521			**1481.0**	GJ/unit		

Design 24

Pure INPUT-OUTPUT TEI	2954.32	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	277,851
PBHA	1844	GJ/unit					
IOBHA	**3276.55**	**GJ/unit**					
	1432.55	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	96.9570			97.0	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1432.5543			**1432.6**	GJ/unit		

Design 25

Pure INPUT-OUTPUT TEI	3095.65	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	291,143
PBHA	1884	GJ/unit					
IOBHA	**3345.00**	**GJ/unit**					
	1461.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	101.5953			101.6	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1501.0856			**1501.1**	GJ/unit		

Design 26

Pure INPUT-OUTPUT TEI	2934.38	GJ/unit		sector	TEI (GJ/$1	DEI (GJ/$100 0)	Construction cost $
PA		GJ/unit		residential	10.6327	0.3490	275,976
PBHA	1489	GJ/unit					
IOBHA	**2911.89**	**GJ/unit**					
	1422.89	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	96.3027			96.3	GJ/unit		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1422.8871			**1422.9**	GJ/unit		

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Design 1

Pure INPUT-OUTPUT TEI	1851.65	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)		construction cost $
PA		GJ/unit		residential building	10.6327	0.3490		174,146
PBHA	974	GJ/unit						
IOBHA	**1871.87**	**GJ/unit**						
	897.87	diff (unmodified pathways)						
	residential building			total (unit)				
direct energy	60.7688			60.8	GJ			
modified pathways (GJ/$1000)	5.4769							
remainder of unmodified pathways (GJ/$1000)	5.1558							
remainder of unmodified pathways (GJ/house)	897.8683			**897.9**	GJ			

Design 2

Pure INPUT-OUTPUT TEI	1859.67	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	174,900
PBHA	1049	GJ/unit					
IOBHA	**1950.76**	**GJ/unit**					
	901.76	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	61.0319			61.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	901.7558			**901.8**	GJ		

Design 3

Pure INPUT-OUTPUT TEI	1845.15	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	173,535
PBHA	929	GJ/unit					
IOBHA	**1823.72**	**GJ/unit**					
	894.72	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	60.5556			60.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	894.7180			**894.7**	GJ		

Design 4

Pure INPUT-OUTPUT TEI	1863.27	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	175,239
PBHA	995	GJ/unit					
IOBHA	**1902.00**	**GJ/unit**					
	907.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	61.1502			61.2	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	903.5036			**903.5**	GJ		

Design 5

Pure INPUT-OUTPUT TEI	1980.08	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	186,225
PBHA	1350	GJ/unit					
IOBHA	**2310.15**	**GJ/unit**					
	960.15	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.9838			65.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	960.1456			**960.1**	GJ		

Design 6

Pure INPUT-OUTPUT TEI	1814.55	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	170,657
PBHA	892	GJ/unit					
IOBHA	**1771.88**	**GJ/unit**					
	879.88	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	59.5513			59.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	879.8795			**879.9**	GJ		

Design 7

Pure INPUT-OUTPUT TEI	1879.39	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	176,755
PBHA	1066	GJ/unit					
IOBHA	**1980.00**	**GJ/unit**					
	914.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	61.6792			61.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	911.3198			**911.3**	GJ		

Design 8

Pure INPUT-OUTPUT TEI	2078.19	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	195,452
PBHA	1654	GJ/unit					
IOBHA	**2661.72**	**GJ/unit**					
	1007.72	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	68.2036			68.2	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1007.7185			**1007.7**	GJ		

Design 9

Pure INPUT-OUTPUT TEI	1831.83	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	172,282
PBHA	990	GJ/unit					
IOBHA	**1878.26**	**GJ/unit**					
	888.26	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	60.1184			60.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	888.2578			**888.3**	GJ		

Design 10

Pure INPUT-OUTPUT TEI	1820.84	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	171,248
PBHA	896	GJ/unit					
IOBHA	**1778.93**	**GJ/unit**					
	882.93	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	59.7575			59.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	882.9266			**882.9**	GJ		

Design 11

Pure INPUT-OUTPUT TEI	1865.74	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	175,471
PBHA	1109	GJ/unit					
IOBHA	**2017.00**	**GJ/unit**					
	908.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	61.2312			61.2	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	904.6997			**904.7**	GJ		

Design 12

Pure INPUT-OUTPUT TEI	1852.04	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	174,183
PBHA	930	GJ/unit					
IOBHA	**1828.06**	**GJ/unit**					
	898.06	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	60.7817			60.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	898.0590			**898.1**	GJ		

Design 13

Pure INPUT-OUTPUT TEI	1842.47	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	173,283
PBHA	951	GJ/unit					
IOBHA	**1852.00**	**GJ/unit**					
	901.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	60.4677			60.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	893.4188			**893.4**	GJ		

Design 14

Pure INPUT-OUTPUT TEI	1826.77	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	171,806
PBHA	977	GJ/unit					
IOBHA	**1866.00**	**GJ/unit**					
	889.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	59.9523			60.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	885.8036			**885.8**	GJ		

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Design 1

Pure INPUT-OUTPUT TEI	1927.79	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	181,307
PBHA	1026	GJ/unit					
IOBHA	**1960.79**	**GJ/unit**					
	934.79	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	63.2677			63.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	934.7892			**934.8**	GJ		

Design 2

Pure INPUT-OUTPUT TEI	1915.54	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	180,155
PBHA	1055	GJ/unit					
IOBHA	**1983.85**	**GJ/unit**					
	928.85	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	62.8657			62.9	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	928.8497			**928.8**	GJ		

Design 3

Pure INPUT-OUTPUT TEI	1968.75	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	185,159
PBHA	1337	GJ/unit					
IOBHA	**2291.65**	**GJ/unit**					
	954.65	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.6118			64.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	954.6495			**954.6**	GJ		

Design 4

Pure INPUT-OUTPUT TEI	1910.42	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	179,673
PBHA	1159	GJ/unit					
IOBHA	**2085.36**	**GJ/unit**					
	926.36	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	62.6975			62.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	926.3646			**926.4**	GJ		

Design 5

Pure INPUT-OUTPUT TEI	1882.06	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	177,006
PBHA	987	GJ/unit					
IOBHA	**1902.00**	**GJ/unit**					
	915.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	61.7668			61.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	912.6140			**912.6**	GJ		

Design 6

Pure INPUT-OUTPUT TEI	1929.32	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	181,451
PBHA	1173	GJ/unit					
IOBHA	**2111.00**	**GJ/unit**					
	938.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	63.3179			63.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	935.5316			**935.5**	GJ		

Design 7

Pure INPUT-OUTPUT TEI	1972.48	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	185,510
PBHA	1193	GJ/unit					
IOBHA	**2153.00**	**GJ/unit**					
	960.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.7343			64.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	956.4592			**956.5**	GJ		

Design 8

Pure INPUT-OUTPUT TEI	1952.16	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	183,599
PBHA	1245	GJ/unit					
IOBHA	**2191.61**	**GJ/unit**					
	946.61	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.0675			64.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	946.6064			**946.6**	GJ		

Design 9

Pure INPUT-OUTPUT TEI	1952.16	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	183,599
PBHA	1245	GJ/unit					
IOBHA	**2191.61**	**GJ/unit**					
	946.61	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.0675			64.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	946.6064			**946.6**	GJ		

Design 10

Pure INPUT-OUTPUT TEI	2013.43	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	189,361
PBHA	1387	GJ/unit					
IOBHA	**2363.31**	**GJ/unit**					
	976.31	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.0781			66.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	976.3143			**976.3**	GJ		

Design 11

Pure INPUT-OUTPUT TEI	1965.82	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	184,884
PBHA	1034	GJ/unit					
IOBHA	**1927.00**	**GJ/unit**					
	893.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.5159			64.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	953.2316			**953.2**	GJ		

Design 12

Pure INPUT-OUTPUT TEI	1932.71	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	181,770
PBHA	1091	GJ/unit					
IOBHA	**2028.18**	**GJ/unit**					
	937.18	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	63.4292			63.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	937.1764			**937.2**	GJ		

Design 13

Pure INPUT-OUTPUT TEI	1897.76	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	178,483
PBHA	1024	GJ/unit					
IOBHA	**1947.00**	**GJ/unit**					
	923.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	62.2822			62.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	920.2291			**920.2**	GJ		

Design 14

Pure INPUT-OUTPUT TEI	2032.33	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	191,139
PBHA	1400	GJ/unit					
IOBHA	**2385.48**	**GJ/unit**					
	985.48	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.6986			66.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	985.4814			**985.5**	GJ		

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Design 1

Pure INPUT-OUTPUT TEI	1974.39	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	185,690
PBHA	1193	GJ/unit					
IOBHA	**2154.00**	**GJ/unit**					
	961.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.7971			64.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	957.3872			**957.4**	GJ		

Design 2

Pure INPUT-OUTPUT TEI	1916.67	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	180,261
PBHA	1037	GJ/unit					
IOBHA	**1969.00**	**GJ/unit**					
	932.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	62.9027			62.9	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	929.3962			**929.4**	GJ		

Design 3

Pure INPUT-OUTPUT TEI	1969.13	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	185,195
PBHA	1145	GJ/unit					
IOBHA	**2099.84**	**GJ/unit**					
	954.84	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.6244			64.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	954.8351			**954.8**	GJ		

Design 4

Pure INPUT-OUTPUT TEI	1979.61	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	186,180
PBHA	1152	GJ/unit					
IOBHA	**2115.00**	**GJ/unit**					
	963.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.9681			65.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	959.9136			**959.9**	GJ		

Design 5

Pure INPUT-OUTPUT TEI	2110.49	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	198,490
PBHA	1684	GJ/unit					
IOBHA	**2707.38**	**GJ/unit**					
	1023.38	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	69.2637			69.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1023.3819			**1023.4**	GJ		

Design 6

Pure INPUT-OUTPUT TEI	1989.68	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	187,128
PBHA	1131	GJ/unit					
IOBHA	**2099.00**	**GJ/unit**					
	968.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	65.2989			65.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	964.8013			**964.8**	GJ		

Design 7

Pure INPUT-OUTPUT TEI	1965.41	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	184,845
PBHA	1119	GJ/unit					
IOBHA	**2072.03**	**GJ/unit**					
	953.03	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.5023			64.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	953.0306			**953.0**	GJ		

Design 8

Pure INPUT-OUTPUT TEI	1973.97	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	185,650
PBHA	1080	GJ/unit					
IOBHA	**2037.18**	**GJ/unit**					
	957.18	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.7832			64.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	957.1810			**957.2**	GJ		

Design 9

Pure INPUT-OUTPUT TEI	1958.22	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	184,169
PBHA	1112	GJ/unit					
IOBHA	**2061.55**	**GJ/unit**					
	949.55	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.2664			64.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	949.5452			**949.5**	GJ		

Design 10

Pure INPUT-OUTPUT TEI	2155.48	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	202,721
PBHA	1187	GJ/unit					
IOBHA	**2235.00**	**GJ/unit**					
	1048.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	70.7402			70.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1045.1963			**1045.2**	GJ		

Design 11

Pure INPUT-OUTPUT TEI	2080.72	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	195,690
PBHA	1519	GJ/unit					
IOBHA	**2527.95**	**GJ/unit**					
	1008.95	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	68.2867			68.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1008.9456			**1008.9**	GJ		

Design 12

Pure INPUT-OUTPUT TEI	2190.00	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	205,967
PBHA	1325	GJ/unit					
IOBHA	**2390.00**	**GJ/unit**					
	1065.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	71.8729			71.9	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1061.9321			**1061.9**	GJ		

Design 13

Pure INPUT-OUTPUT TEI	1961.92	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	184,517
PBHA	1031	GJ/unit					
IOBHA	**1982.34**	**GJ/unit**					
	951.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	64.3878			64.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	951.3394			**951.3**	GJ		

Design 14

Pure INPUT-OUTPUT TEI	1994.92	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	187,620
PBHA	1112	GJ/unit					
IOBHA	**2079.34**	**GJ/unit**					
	967.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	65.4706			65.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	967.3380			**967.3**	GJ		

Design 15

Pure INPUT-OUTPUT TEI	1994.92	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	187,620
PBHA	1112	GJ/unit					
IOBHA	**2079.34**	**GJ/unit**					
	967.34	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	65.4706			65.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	967.3380			**967.3**	GJ		

Design 16

Pure INPUT-OUTPUT TEI	2002.73	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	188,355
PBHA	1149	GJ/unit					
IOBHA	**2120.13**	**GJ/unit**					
	971.13	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	65.7271			65.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	971.1275			**971.1**	GJ		

Design 17

Pure INPUT-OUTPUT TEI	2032.43	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	191,148
PBHA	1236	GJ/unit					
IOBHA	**2221.53**	**GJ/unit**					
	985.53	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.7017			66.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	985.5278			**985.5**	GJ		

Design 18

Pure INPUT-OUTPUT TEI	2364.63	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	222,391
PBHA	1757	GJ/unit					
IOBHA	**2903.61**	**GJ/unit**					
	1146.61	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	77.6041			77.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1146.6116			**1146.6**	GJ		

Design 19

Pure INPUT-OUTPUT TEI	2173.70	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	204,434
PBHA	1415	GJ/unit					
IOBHA	**2469.03**	**GJ/unit**					
	1054.03	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	71.3379			71.3	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1054.0282			**1054.0**	GJ		

Design 20

Pure INPUT-OUTPUT TEI	2062.71	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	193,996
PBHA	1324	GJ/unit					
IOBHA	**2324.21**	**GJ/unit**					
	1000.21	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.6955			67.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1000.2116			**1000.2**	GJ		

Design 21

Pure INPUT-OUTPUT TEI	2097.50	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	197,268
PBHA	1397	GJ/unit					
IOBHA	**2414.08**	**GJ/unit**					
	1017.08	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	68.8373			68.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1017.0815			**1017.1**	GJ		

Design 22

Pure INPUT-OUTPUT TEI	2014.78	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	189,488
PBHA	1177	GJ/unit					
IOBHA	**2153.97**	**GJ/unit**					
	976.97	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.1225			66.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	976.9691			**977.0**	GJ		

Design 23

Pure INPUT-OUTPUT TEI	2085.35	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	196,125
PBHA	1424	GJ/unit					
IOBHA	**2435.19**	**GJ/unit**					
	1011.19	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	68.4385			68.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1011.1884			**1011.2**	GJ		

Design 24

Pure INPUT-OUTPUT TEI	2197.20	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	206,645
PBHA	1189	GJ/unit					
IOBHA	**2257.00**	**GJ/unit**					
	1068.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	72.1094			72.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1065.4278			**1065.4**	GJ		

Design 25

Pure INPUT-OUTPUT TEI	2043.84	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	192,221
PBHA	1161	GJ/unit					
IOBHA	**2152.06**	**GJ/unit**					
	991.06	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.0761			67.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	991.0600			**991.1**	GJ		

Design 26

Pure INPUT-OUTPUT TEI	2206.51	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	207,520
PBHA	1236	GJ/unit					
IOBHA	**2305.94**	**GJ/unit**					
	1069.94	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	72.4148			72.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1069.9391			**1069.9**	GJ		

Design 27

Pure INPUT-OUTPUT TEI	2071.94	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	194,864
PBHA	1206	GJ/unit					
IOBHA	**2210.69**	**GJ/unit**					
	1004.69	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.9984			68.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1004.6869			**1004.7**	GJ		

Design 28

Pure INPUT-OUTPUT TEI	2042.24	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	192,071
PBHA	1119	GJ/unit					
IOBHA	**2109.29**	**GJ/unit**					
	990.29	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.0238			67.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	990.2866			**990.3**	GJ		

Design 29

Pure INPUT-OUTPUT TEI	2002.73	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	188,355
PBHA	1149	GJ/unit					
IOBHA	**2120.13**	**GJ/unit**					
	971.13	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	65.7271			65.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	971.1275			**971.1**	GJ		

Design 30

Pure INPUT-OUTPUT TEI	2054.40	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	193,214
PBHA	1145	GJ/unit					
IOBHA	**2141.18**	**GJ/unit**					
	996.18	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.4227			67.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	996.1797			**996.2**	GJ		

Design 31

Pure INPUT-OUTPUT TEI	2221.21	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	208,903
PBHA	1173	GJ/unit					
IOBHA	**2253.00**	**GJ/unit**					
	1080.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	72.8974			72.9	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1077.0697			**1077.1**	GJ		

Design 32

Pure INPUT-OUTPUT TEI	2364.63	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	222,391
PBHA	1759	GJ/unit					
IOBHA	**2905.61**	**GJ/unit**					
	1146.61	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	77.6041			77.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1146.6116			**1146.6**	GJ		

Design 33

Pure INPUT-OUTPUT TEI	2033.23	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	191,223
PBHA	1010	GJ/unit					
IOBHA	**1995.91**	**GJ/unit**					
	985.91	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.7279			66.7	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	985.9145			**985.9**	GJ		

Design 34

Pure INPUT-OUTPUT TEI	2071.94	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	194,864
PBHA	1206	GJ/unit					
IOBHA	**2210.69**	**GJ/unit**					
	1004.69	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.9984			68.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1004.6869			**1004.7**	GJ		

Design 35

Pure INPUT-OUTPUT TEI	2022.03	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	190,170
PBHA	1059	GJ/unit					
IOBHA	**2039.49**	**GJ/unit**					
	980.49	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.3604			66.4	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	980.4854			**980.5**	GJ		

Design 36

Pure INPUT-OUTPUT TEI	2137.01	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	200,984
PBHA	1416	GJ/unit					
IOBHA	**2452.24**	**GJ/unit**					
	1036.24	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	70.1340			70.1	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1036.2406			**1036.2**	GJ		

Design 37

Pure INPUT-OUTPUT TEI	2030.04	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	190,923
PBHA	1010	GJ/unit					
IOBHA	**1997.00**	**GJ/unit**					
	987.00	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	66.6232			66.6	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	984.3677			**984.4**	GJ		

Design 38

Pure INPUT-OUTPUT TEI	2187.62	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	205,744
PBHA	1346	GJ/unit					
IOBHA	**2406.78**	**GJ/unit**					
	1060.78	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	71.7950			71.8	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1060.7824			**1060.8**	GJ		

Design 39

Pure INPUT-OUTPUT TEI	2071.94	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	194,864
PBHA	1206	GJ/unit					
IOBHA	**2210.69**	**GJ/unit**					
	1004.69	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	67.9984			68.0	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1004.6869			**1004.7**	GJ		

Design 40

Pure INPUT-OUTPUT TEI	2362.17	GJ/unit		sector	TEI (GJ/$1000)	DEI (GJ/$1000)	construction cost $
PA		GJ/unit		residential building	10.6327	0.3490	222,160
PBHA	1386	GJ/unit					
IOBHA	**2531.42**	**GJ/unit**					
	1145.42	diff (unmodified pathways)					
	residential building			total (unit)			
direct energy	77.5235			77.5	GJ		
modified pathways (GJ/$1000)	5.4769						
remainder of unmodified pathways (GJ/$1000)	5.1558						
remainder of unmodified pathways (GJ/house)	1145.4206			**1145.4**	GJ		

APPENDIX E- SPACE-CONDITIONING, EMBODIED AND NET EMISSION CALCULATIONS

Kingston 5-6 star

Design Number	Floor type	Star rating	Cost of thermal performance improvement ($'00)	Cost of improvement/ m2	Change in Energy Intensity (GJ)	Base IOBHA	New IOBHA GJ	Change in embodied energy	% increase in embodied energy
1	S	5.1	$15	13.86	5.18	1531	1545	13.18	0.86
2	S	5.1	($8.42)	-7.72	-20.82	1531	1506	-25.335	-1.65
3	T	5.1	$15	13.99	25.95	1587	1620	32.62	2.05
4	T	5.2	-$1.65	-1.51	-1.31	1587	1585	-2.38	-0.15
5	T	5.2	$20	17.94	29	1587	1626	38.62	2.43
6	S	5.2	($4.42)	-4.06	-7.35	1531	1522	-9.38	-0.61
7	S	5.3	$32	29.36	90.93	1531	1639	107.62	7.03
8	T	5.4	$111	101.83	209.65	1587	1854	267	16.80
9	S	5.4	$64	58.72	104.44	1531	1668	136.62	8.92
10	T	5.6	$155.00	142.20	478.21	1587	2144	556.62	35.07
11	S	5.7	$6.40	5.87	22.84	1531	1558	26.62	1.74
12	S	5.7	$36.60	33.58	41.46	1531	1592	60.62	3.96
13	S	5.9	$74	67.89	135.42	1531	1705	173.62	11.34
14	T	5.9	$39	35.52	21.65	1587	1628	40.62	2.56
15	S	5.9	$80.00	73.39	98.75	1531	1672	140.62	9.18
16	T	5.9	$107	98.17	253	1587	1895	307.62	19.38

Kingston 5-6 star

Design Number	Annualised embodied emissions of improvement (kg)	Annualised total embodied emissions (kg)	Heating/cooling MJ/m2 per annum	Annual heating/cooling energy (MJ)	Annual heating/cooling emissions (kg)	Savings in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	34	4016	256	18483	616	240	-206
2	-66	3916	258	18628	621	235	-301
3	85	4212	257	18555	619	237	-153
4	-6	4121	252	18194	606	250	-256
5	100	4228	247	17833	594	262	-161
6	-24	3957	251	18122	604	252	-276
7	280	4261	245	17689	590	266	13
8	693	4820	238	17184	573	283	410
9	355	4337	239	17256	575	281	74
10	1447	5574	227	16389	546	310	1138
11	69	4051	217	15667	522	334	-265
12	158	4139	221	15956	532	324	-167
13	451	4433	208	15018	501	355	96
14	106	4233	202	14584	486	370	-264
15	366	4347	206	14873	496	360	5
16	800	4927	202	14584	486	370	430

Kingston 6-7 star

Design Number	Floor type	Star rating	Cost of thermal performance improvement ($'00)	Cost of improvement/ m2	Change in energy Intensity (GJ)	Base IOBHA (GJ)	New IOBHA (GJ)	Change in embodied energy	% increase in embodied energy
1	T	6.1	60	55.05	116.72	1587	1734	146.62	9.24
2	S	6.1	112	102.75	114	1531	1703	171.62	11.21
3	S	6.1	97	88.99	146	1531	1727	195.62	12.77
4	T	6.2	68	62.39	124.96	1587	1746	158.62	9.99
5	S	6.2	47	43.24	66	1531	1622	90.62	5.92
6	S	6.3	52	47.88	75	1531	1633	101.62	6.64
7	T	6.3	86	78.90	174.58	1587	1806	218.62	13.77
8	T	6.3	103	94.50	141.96	1587	1781	193.62	12.20
9	S	6.6	108	99.08	166	1531	1753	221.62	14.47
10	S	6.6	116	106.42	174	1531	1765	233.62	15.26
11	S	6.7	112	102.75	174	1531	1763	231.62	15.12
12	T	6.7	148	135.78	289.5	1587	1953	365.62	23.03
13	T	6.7	104	95.41	203	1587	1843	255.62	16.10
14	S	6.8	117	107.34	99	1531	1691	159.62	10.42
15	S	6.8	126	115.60	121	1531	1717	185.62	12.12
16	T	6.8	153	140.37	299	1587	1964	376.62	23.73
17	S	6.9	132.00	121.10	164	1531	1763	231.62	15.12
18	S	6.9	115.00	105.50	151	1531	1742	210.62	13.75
19	S	6.9	123	112.84	199	1531	1794	262.62	17.15
20	T	6.9	153	140.37	213	1587	1878	290.62	18.31
21	T	6.9	148	135.78	411	1587	2074	486.62	30.66
22	T	6.9	103	94.50	143	1587	1782	194.62	12.26

Kingston 6-7 star

Design Number	Annualised embodied emissions of improvement (kg)	Annualised total embodied emissions (kg)	Heating/ cooling MJ/m2 per annum	Annual heating/cooling energy (MJ)	Annual heating/cooling emissions (kg)	Savings in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	381	4508	195	14079	469	387	-5
2	446	4428	196	14151	472	384	62
3	509	4490	194	14007	467	389	120
4	412	4540	191	13790	460	396	16
5	236	4217	190	13718	457	399	-163
6	264	4246	187	13501	450	406	-142
7	568	4696	185	13357	445	411	158
8	503	4631	185	13357	445	411	93
9	576	4558	169	12202	407	449	127
10	607	4589	167	12057	402	454	153
11	602	4584	166	11985	400	456	146
12	951	5078	164	11841	395	461	489
13	665	4792	163	11769	392	464	201
14	415	4397	159	11480	383	473	-58
15	483	4464	156	11263	375	481	2
16	979	5106	160	11552	385	471	508
17	602	4584	154	11119	371	485	117
18	548	4529	154	11119	371	485	62
19	683	4664	155	11191	373	483	200
20	756	4883	151	10902	363	493	263
21	1265	5392	151	10902	363	493	773
22	506	4633	153	11047	368	488	18

Kingston 7-8 star

Design Number	Floor type	Star rating	Cost of thermal performance improvement ($'00)	Cost of improvement /m2	change in energy intensity (GJ)	Base IOBHA (GJ)	New IOBHA (GJ)	Change in embodied energy	% increase in embodied energy
1	T	7	205	188.07	165	1587	1857	269.62	16.99
2	S	7	170	155.96	173	1531	1792	260.62	17.02
3	S	7.1	158	144.95	192	1531	1795	263.62	17.21
4	S	7.1	188	172.48	195	1531	1823	291.62	19.04
5	T	7.1	190	174.31	517	1587	2201	613.62	38.66
6	S	7.1	195	178.90	216	1531	1848	316.62	20.68
7	S	7.1	148	135.78	224	1531	1832	300.62	19.63
8	S	7.1	173	158.72	387	1531	2009	477.62	31.19
9	S	7.1	158	144.95	320	1531	1933	401.62	26.23
10	S	7.1	166	152.29	366	1531	1983	451.62	29.49
11	T	7.2	247	226.61	239	1587	1953	365.62	23.03
12	S	7.2	120	110.09	115	1531	1708	176.62	11.53
13	S	7.3	180	165.14	191	1531	1815	283.62	18.52
14	S	7.4	129	118.35	115	1531	1713	181.62	11.86
15	T	7.4	288	264.22	321	1587	2056	468.62	29.52
16	S	7.4	148	135.78	137	1531	1745	213.62	13.95
17	S	7.4	119	109.17	205	1531	1798	266.62	17.41
18	S	7.4	224	205.50	362	1531	2009	477.62	31.19
19	S	7.5	282	258.72	160	1531	1836	304.62	19.89
20	S	7.6	289	265.14	182	1531	1862	330.62	21.59
21	S	7.6	271	248.62	191	1531	1862	330.62	21.59
22	T	7.6	191	175.23	512	1587	2197	609.62	38.40
23	T	7.7	248	227.52	214	1587	1928	340.62	21.46
24	S	7.8	179	164.22	198	1531	2014	482.62	31.52
25	S	7.9	246	225.69	356	1531	1913	381.91	24.94
26	T	7.9	335	307.34	557	1587	2316	728.62	45.90
27	S	7.9	295	270.64	361	1531	2044	512.62	33.47
28	S	8.1	378	346.79	361	1531	2087	555.62	36.28

Kingston 7-8

Design Number	Annualised embodied emissions of improvement (kg)	Annualised total embodied emissions (kg)	Heating/cooling MJ/m2 per annum	Annual heating/cooling energy (MJ)	Annual heating/cooling emissions (kg)	Savings in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	701	4828	146	10541	351	505	196
2	678	4659	145	10469	349	507	171
3	685	4667	143	10325	344	512	174
4	758	4740	142	10252	342	514	244
5	1595	5723	145	10469	349	507	1088
6	823	4805	141	10180	339	517	307
7	782	4763	144	10397	347	509	272
8	1242	5223	139	10036	335	521	720
9	1044	5026	143	10325	344	512	532
10	1174	5156	139	10036	335	521	653
11	951	5078	135	9747	325	531	420
12	459	4441	137	9891	330	526	-67
13	737	4719	133	9603	320	536	201
14	472	4454	123	8881	296	560	-88
15	1218	5346	123	8881	296	560	658
16	555	4537	125	9025	301	555	0
17	693	4675	127	9169	306	550	143
18	1242	5223	123	8881	296	560	682
19	792	4774	118	8520	284	572	220
20	860	4841	117	8447	282	574	285
21	860	4841	115	8303	277	579	280
22	1585	5712	116	8375	279	577	1008
23	886	5013	108	7798	260	596	290
24	1255	5236	101	7292	243	613	642
25	993	4975	95	6859	229	627	366
26	1894	6022	100	7220	241	615	1279
27	1333	5314	95	6859	229	627	705
28	1445	5426	87	6281	209	647	798

Crimson 5-6 star

Design	Star rating	Floor type	Cost of thermal performance improvement ($'00)	Cost/m2 of improvement	Change in energy intensity (GJ)	Base IOBHA	New IOBHA	Change in embodied energy	% change in embodied energy
1	5.1	t	141	80.57	335	2499.99	2906	406.01	16.24
2	5.2	c	45	25.71	122	2489.85	2633	143.15	5.75
3	5.3	c	73	41.71	137	2489.85	2633	143.15	5.75
4	5.3	c	45	25.71	53.0	2489.85	2565	75.15	3.02
5	5.3	t	38	21.71	107	2499.99	2625	125.01	5.00
6	5.3	t	-14	-8.00	28	2499.99	2463	-36.99	-1.48
7	5.4	c	12	6.86	29	2489.85	2524	34.15	1.37
8	5.7	t	88	50.29	24	2499.99	2565	65.01	2.60
9	5.8	t	79	45.14	151	2499.99	2690	190.01	7.60
10	5.9	t	136	77.71	334.0	2499.99	2902	402.01	16.08
11	5.9	t	98	56.00	168	2499.99	2717	217.01	8.68
12	5.9	t	122	69.71	116	2499.99	2678	178.01	7.12

Crimson 5-6 star

Design	Annualised embodied emissions of improvement	Total annualised embodied emissions	Heating/cooling MJ/m2 per annum	Annual heating/cooling energy	Annual heating/cooling emissions (kg)	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	1056	7556	229	25327	844	317	739
2	372	6846	228	25217	841	320	52
3	372	6846	222	24553	818	343	30
4	195	6669	222	24553	818	343	-147
5	325	6825	222	24553	818	343	-18
6	-96	6404	222	24553	818	343	-439
7	89	6562	215	23779	793	368	-280
8	169	6669	201	22231	741	420	-251
9	494	6994	194	21456	715	446	48
10	1045	7545	186	20572	686	475	570
11	564	7064	186	20572	686	475	89
12	463	6963	186	20572	686	475	-12

Crimson 6-7 stars

Design	Star rating	Floor type	Cost of thermal performance improvement ('00's)	Cost/m2	Change in energy intensity	Base IOBHA	New IOBHA	Change in embodied energy	% change in embodied energy
1	6	t	128	73.14	234	2499.99	2799	299.01	11.96
2	6	s	61	34.86	86	2489.85	2606	116.15	4.66
3	6	s	89	50.86	169	2489.85	2704	214.15	8.60
4	6.1	t	124	70.86	130	2499.99	2693	193.01	7.72
5	6.2	s	79	45.14	103	2489.85	2633	143.15	5.75
6	6.2	t	135	77.14	196	2499.99	2764	264.01	10.56
7	6.4	t	135	77.14	196.0	2499.99	2764	264.01	10.56
8	6.4	t	177	101.14	369	2499.99	2954	454.01	18.16
9	6.4	s	131	74.86	213	2489.85	2769	279.15	11.21
10	6.5	t	88	50.29	169.0	2499.99	2726	226.01	9.04
11	6	t	195	111.43	386.0	2499.99	2986	486.01	19.44
12	6.6	s	185	105.71	161.0	2489.85	2746	256.15	10.29
13	6.6	t	137	78.29	147.0	2499.99	2716	216.01	8.64
14	6.6	s	149	85.14	230.0	2489.85	2796	306.15	12.30
15	6.6	s	149	85.14	230.0	2489.85	2796	306.15	12.30
16	6.7	t	246	140.57	550	2499.99	3176	676.01	27.04
17	6.7	t	177	101.14	126.0	2499.99	2716	216.01	8.64
18	6.8	s	203	116.00	184.0	2489.85	2778	288.15	11.57
19	6.8	t	190	108.57	155	2499.99	2742	242.01	9.68
20	6.9	t	275	157.14	702	2499.99	3343	843.01	33.72
21	6.9	s	159	90.86	263.0	2489.85	2835	345.15	13.86
22	6.9	s	239	136.57	222	2489.85	2834	344.15	13.82
23	6.7	t	162	92.57	134	2499.99	2717	217.01	8.68
24	6.9	s	224	128.00	233	2489.85	2837	347.15	13.94

Crimson 6-7 star

Design	Annualised embodied emissions of improvement (kg)	Total annualised embodied emissions (kg)	Heating/cooling MJ/m2 per annum	Annual heating/cooling energy (MJ)	Annual heating/cooling emissions (kg)	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	777	7277	156	17254	575	586	192
2	302	6776	153	16922	564	597	-295
3	557	7030	182	20129	671	490	67
4	502	7002	142	15705	524	637	-136
5	372	6846	146	16148	538	623	-251
6	686	7186	183	20240	675	486	200
7	686	7186	146	16148	538	623	64
8	1180	7680	143	15816	527	634	547
9	726	7199	179	19797	660	501	225
10	588	7088	159	17585	586	575	13
11	1264	7764	158	17475	582	579	685
12	666	7140	153	16922	564	597	69
13	562	7062	152	16811	560	601	-39
14	796	7270	139	15373	512	649	147
15	796	7270	152	16811	560	601	195
16	1758	8258	140	15484	516	645	1113
17	562	7062	133	14710	490	671	-109
18	749	7223	132	14599	487	674	75
19	629	7129	128	14157	472	689	-60
20	2192	8692	132	14599	487	674	1517
21	897	7371	128	14157	472	689	208
22	895	7368	129	14267	476	685	209
23	564	7064	107	11834	394	767	-202
24	903	7376	106	11724	391	770	132

Crimson 7-8 stars

Design	Star rating	Floor type	Cost of thermal performance improvement (‘00’s)	Cost/m2	Change in energy intensity	Base IOBHA (GJ)	New IOBHA (GJ)	Change in embodied energy (IOBHA)	% change in embodied energy
1	7	s	248	141.71	225	2489.85	2842	352.15	14.14
2	7	s	184	105.14	196	2489.85	2782	292.15	11.73
3	7	s	224	128.00	442	2489.85	3046	556.15	22.34
4	7	s	224	128.00	138	2489.85	2742	252.15	10.13
5	7	t	306	174.86	208	2499.99	2864	364.01	14.56
6	7	t	336	192.00	307	2499.99	2979	479.01	19.16
7	7.1	s	234	133.71	628	2489.85	3238	748.15	30.05
8	7.1	t	227	129.71	501	2499.99	3108	608.01	24.32
9	7.1	s	319	182.29	430	2489.95	3083	593.05	23.82
10	7.1	s	228	130.29	222	2489.85	2839	349.15	14.02
11	7.1	s	274	156.57	229	2499.99	2909	409.01	16.36
12	7.2	s	307	175.43	311	2489.85	2958	468.15	18.80
13	7.2	t	325	185.71	392	2499.99	3058	558.01	22.32
14	7.4	s	169	96.57	264	2489.95	2840	350.05	14.06
15	7.4	s	224	128.00	134	2489.95	2738	248.05	9.96
16	7.4	t	275	157.14	702	2499.99	3338	838.01	33.52
17	7.5	s	411	234.86	224	2489.95	2925	435.05	17.47
18	7.5	s	398	227.43	195	2489.95	2889	399.05	16.03
19	7.6	s	229	130.86	134	2489.95	2741	251.05	10.08
20	7.6	t	336	192.00	306	2499.99	2978	478.01	19.12
21	7.8	s	307	175.43	311	2489.95	2958	468.05	18.80
22	7.8	s	358	204.57	167	2499.99	3141	641.01	25.64
23	7.8	t	483	276.00	742	2499.99	3490	990.01	39.60
24	7.8	t	389	222.29	387	2499.99	3277	777.01	31.08
25	8.1	s	522	298.29	627	2489.95	3345	855.05	34.34
26	7.6	s	370	211.43	232	2489.95	2912	422.05	16.95

Crimson 7-8 stars

Design	Annualised embodied emissions of improvement (kg)	Annualised embodied emissions based on 25 year life (kg)	Heating/cooling MJ/m2 per annum	Annual heating/cooling energy (MJ)	Annual heating/cooling emissions (kg)	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	916	7389	133	14710	490	671	245
2	760	7233	133	14710	490	671	89
3	1446	7920	133	14710	490	671	775
4	656	7129	133	14710	490	671	-15
5	946	7446	133	14710	490	671	276
6	1245	7745	133	14710	490	671	575
7	1945	8419	128	14157	472	689	1256
8	1581	8081	128	14157	472	689	892
9	1542	8016	128	14157	472	689	853
10	908	7381	128	14157	472	689	219
11	1063	7563	128	14157	472	689	374
12	1217	7691	122	13493	450	711	506
13	1451	7951	122	13493	450	711	740
14	910	7384	117	12940	431	730	180
15	645	7119	117	12940	431	730	-85
16	2179	8679	117	12940	431	730	1449
17	1131	7605	109	12055	402	759	372
18	1038	7511	109	12055	402	759	278
19	653	7127	106	11724	391	770	-117
20	1243	7743	106	11724	391	770	473
21	1217	7691	93	10286	343	818	399
22	1667	8167	93	10286	343	818	848
23	2574	9074	93	10286	343	818	1756
24	2020	8520	93	10286	343	818	1202
25	2223	8697	78	8627	288	873	1350
26	1097	7571	106	11724	391	770	327

Hickman 5-6 stars

Design number	Star rating	Floor type	Cost of improvement ('00s)	Cost of improvement ($/m2)	Change in energy intensity	Base IOBHA	New IOBHA	Change in IOBHA	% change in total embodied energy
1	5	s	14	$11	37	1828	1872	44	2.4
2	5.1	t	22	$17	49	1890	1951	61	3.2
3	5.1	s	8	$6	-8	1828	1824	-4	-0.2
4	5.3	s	25	$20	58	1828	1902	74	4.0
5	5.3	t	135	$106	350	1890	2310	420	22.2
6	5.4	s	(21)	-$17	-45	1828	1772	-56	-3.1
7	5.6	s	40	$31	129	1828	1980	152	8.3
8	5.6	t	227	$179	654	1890	2661	771	40.8
9	5.6	t	(4)	-$3	-10	1890	1878	-12	-0.6
10	5.6	s	(15)	-$12	-41	1828	1779	-49	-2.7
11	5.7	t	28	$22	109	1890	2017	127	6.7
12	5.7	s	15	$12	-7	1828	1828	0	0.0
13	5.8	s	6	$5	14	1828	1852	24	1.3
14	5.8	t	(9)	-$7	-23	1890	1866	-24	-1.3

Hickman 5-6 stars

Design number	Annualised embodied emissions of improvement (kg)	Total embodied emissions annualised based on 25 year life (kg)	Heating/cooling energy MJ/m2 per annum	Total annual heating/cooling (MJ)	Annual heating/cooling emissions kg	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	114	4867	248	23064	769	288	-174
2	159	5073	245	22785	760	298	-139
3	-10	4742	245	22785	760	298	-308
4	192	4945	232	21576	719	338	-145
5	1092	6006	232	21576	719	338	754
6	-146	4607	227	21111	704	353	-499
7	395	5148	215	19995	667	391	5
8	2005	6919	215	19995	667	391	1614
9	-31	4883	215	19995	667	391	-422
10	-127	4625	215	19995	667	391	-518
11	330	5244	207	19251	642	415	-85
12	0	4753	207	19251	642	415	-415
13	62	4815	204	18972	632	425	-362
14	-62	4852	204	18972	632	425	-487

Hickman 6-7 stars

Design number	Star rating	Floor type	Cost of improvement ('00s)	Cost of improvement ($/m2)	Change in energy intensity	Base IOBHA	New IOBHA	Change in IOBHA	% change in total embodied energy
1	6	t	$86	$68	26	1890	1961	71	3.8
2	6.1	s	$74	$58	118	1828	1984	156	8.5
3	6.2	t	$124	$98	337	1890	2292	402	21.3
4	6.2	t	$70	$55	159	1890	2085	195	10.3
5	6.3	s	43	$34	50	1828	1902	74	4.0
6	6.4	t	$87	$69	173	1890	2111	221	11.7
7	6.5	t	$128	$101	193	1890	2153	263	13.9
8	6.6	t	$109	$86	245	1890	2192	302	16.0
9	6.6	t	$109	$86	245	1890	2192	302	16.0
10	6.8	t	166	$131	387	1890	2363	473	25.0
11	6.9	s	122	$96	97	1828	1927	99	5.4
12	6.9	s	$91	$72	154	1828	2028	200	10.9
13	6.9	s	$58	$46	87	1828	1947	119	6.5
14	6.9	t	$184	$145	900	1890	2385	495	26.2

Hickman 6-7 stars

Design number	Annualised embodied emissions of improvement (kg)	Total embodied emissions annualised based on 25 year life (kg)	Heating/cooling energy MJ/m2 per annum	Total annual heating/cooling energy (MJ)	Annual heating/cooling emissions kg	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	185	5099	192	17856	595	462	-277
2	406	5158	187	17391	580	477	-72
3	1045	5959	181	16833	561	496	549
4	507	5421	181	16833	561	496	11
5	192	4945	179	16647	555	502	-310
6	575	5489	170	15810	527	530	45
7	684	5598	164	15252	508	549	135
8	785	5699	162	15066	502	555	230
9	785	5699	162	15066	502	555	230
10	1230	6144	150	13950	465	592	638
11	257	5010	140	13020	434	623	-366
12	520	5273	140	13020	434	623	-103
13	309	5062	140	13020	434	623	-314
14	1287	6201	140	13020	434	623	664

Hickman 7-8 stars

Design number	Star rating	Floor type	Cost of improvement ('00s)	Cost of improvement ($/m2)	Change in energy intensity	Base IOBHA	New IOBHA	Change in IOBHA	% change in total embodied energy
1	7.1	t	$130	$102	193	1890	2154	264	14.0
2	7.1	s	$75	$59	100	1828	1969	141	7.7
3	7.1	s	$125	$98	208	1828	2099	271	14.8
4	7.1	t	$135	$106	152	1890	2155	265	14.0
5	7.3	t	$258	$203	684	1890	2707	817	43.2
6	7.3	s	$144	$113	194	1828	2099	271	14.8
7	7.3	s	$121	$95	182	1828	2072	244	13.3
8	7.3	s	$129.00	$102	143	1828	2037	209	11.4
9	7.3	s	$115.00	$91	175	1828	2062	234	12.8
10	7.4	t	$300	$236	187	1890	2235	345	18.3
11	7.4	t	$230	$181	519	1890	2528	638	33.8
12	7.4	t	$332.00	$261	325	1890	2390	500	26.5
13	7.4	s	$118	$93	94	1828	1982	154	8.4
14	7.4	s	$149	$117	175	1828	2079	251	13.7
15	7.4	s	$149.00	$117	175	1828	2079	251	13.7
16	7.6	s	$156	$123	212	1828	2120	292	16.0
17	7.7	s	$184	$145	299	1828	2221	393	21.5
18	7.7	t	$497	$391	757	1890	2903	1013	53.6
19	7.8	t	$317	$250	415	1890	2469	579	30.6
20	7.8	s	$213	$168	387	1828	2324	496	27.1
21	7.9	s	$245	$193	460	1828	2414	586	32.1
22	7.8	s	$168	$132	240	1828	2154	326	17.8
23	7.9	s	$234	$184	487	1828	2435	607	33.2
24	7.9	s	$339	$267	252	1828	2257	429	23.5
25	8	s	$195	$154	224	1828	2152	324	17.7
26	8.1	s	$348	$274	236	1828	2306	416	22.0
27	8.1	s	$221	$174	269	1828	2211	383	21.0
28	8.1	s	$194	$153	182	1828	2109	281	15.4
29	8.1	s	$156	$123	212	1828	2120	292	16.0
30	8.1	s	$205	$161	208	1828	2141	313	17.1
31	8.1	s	$362	$285	236	1828	2253	425	23.2
32	8.2	s	$497	$391	759	1828	2906	1016	53.8
33	8.2	s	$181.00	$143	73	1828	1996	168	9.2
34	8.2	s	$221.00	$174	269	1828	2211	383	21.0
35	8.3	s	$175	$138	122	1828	2039	211	11.5
36	8.4	s	$283	$223	479	1828	2452	624	34.1
37	8.4	s	$182	$143	72	1828	1997	169	9.2
38	8.9	s	$330	$260	409	1828	2407	579	31.7
39	8.7	s	$221	$174	269	1828	2211	383	21.0
40	8.9	s	$494	$389	449	1828	2531	703	38.5

Hickman 7-8 stars

Design number	Annualised embodied emissions of improvement (kg)	Total embodied emissions annualised based on 25 year life	Heating/cooling energy MJ/m2 per annum	Total annual heating/cooling MJ	Annual heating/cooling emissions kg	Reduction in heating/cooling emissions (kg)	Savings in net emissions (kg)
1	686	5600	135	12555	419	639	48
2	367	5119	135	12555	419	639	-272
3	705	5457	135	12555	419	639	66
4	689	5603	135	12555	419	639	51
5	2124	7038	126	11718	391	666	1458
6	705	5457	126	11718	391	666	38
7	634	5387	126	11718	391	666	-32
8	543	5296	126	11718	391	666	-123
9	608	5361	126	11718	391	666	-58
10	897	5811	116	10788	360	697	200
11	1659	6573	116	10788	360	697	961
12	1300	6214	116	10788	360	697	603
13	400	5153	116	10788	360	697	-297
14	653	5405	116	10788	360	697	-45
15	653	5405	116	10788	360	697	-45
16	759	5512	107	9951	332	725	34
17	1022	5775	101	9393	313	744	278
18	2634	7548	101	9393	313	744	1890
19	1505	6419	97	9021	301	756	749
20	1290	6042	97	9021	301	756	533
21	1524	6276	93	8649	288	769	755
22	848	5600	97	9021	301	756	91
23	1578	6331	93	8649	288	769	810
24	1115	5868	93	8649	288	769	347
25	842	5595	86	7998	267	790	52
26	1082	5996	85	7905	264	794	288
27	996	5749	85	7905	264	794	202
28	731	5483	85	7905	264	794	-63
29	759	5512	85	7905	264	794	-34
30	814	5567	85	7905	264	794	20
31	1105	5858	85	7905	264	794	312
32	2642	7556	77	7161	239	818	1823
33	437	5190	77	7161	239	818	-382
34	996	5749	77	7161	239	818	178
35	549	5301	75	6975	233	825	-276
36	1622	6375	68	6324	211	846	776
37	439	5192	68	6324	211	846	-407
38	1505	6258	42	3906	130	927	579
39	996	5749	56	5208	174	883	112
40	1828	6581	42	3906	130	927	901

APPENDIX F –BENEFIT-COST CALCULATIONS

Electricity and gas prices series

ELECTRICITY PRICES	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Residential												
Network	97	100	102	105	106	107	108	109	110	111	111	111
Retail operating	10	10	10	10	10	11	11	11	11	11	11	11
TOTAL price no C price (c/kWh)	20.0	19.7	22.1	22.5	22.8	23.0	23.1	23.5	23.4	24.0	24.2	24.5
S/MJ	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
TOTAL price High	20.0	20.0	23.3	23.6	23.8	25.6	25.8	26.2	26.5	26.9	27.2	27.8
S/MJ	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08

ELECTRICITY PRICES	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Residential														
Network	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Retail operating	11	11	11	12	12	12	12	12	12	12	12	13	13	13
TOTAL price no C price (c/kWh)	24.8	25.3	25.7	26.2	26.5	27.0	27.8	28.2	28.5	28.9	29.7	29.5	30.3	30.8
S/MJ	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09
TOTAL price High	28.6	28.9	29.6	29.9	30.1	30.2	30.6	30.3	30.8	31.3	32.0	32.4	33.3	33.3
S/MJ	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09

GAS PRICES	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Residential												
TOTAL price no C price $/GJ	20.5	21.1	22.9	23.3	23.9	24.5	25.0	25.5	26.1	26.3	26.5	26.7
S/MJ	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03
TOTAL price High	20.5	21.1	23.3	23.7	24.4	26.2	26.8	27.5	28.1	28.4	28.8	29.1
S/MJ	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03

GAS PRICES	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Residential														
TOTAL price no C price $/GJ	27.0	27.2	27.5	27.8	28.0	28.3	28.6	28.9	29.2	29.6	29.9	30.3	30.6	31.0
S/MJ	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
TOTAL price High	29.5	29.9	30.4	30.8	31.3	31.8	32.3	32.8	33.3	33.9	34.5	35.1	35.7	35.7
S/MJ	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04

Kingston 6 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value of energy savings	$9,440.61	Net present value of energy savings	$2,697.32	Net present value of energy savings	$5,138.53
Net present value of costs	$4,392.52	Net present value of costs	$4,392.52	Net present value of costs	$4,392.52
BCR	2.15	BCR	0.61	BCR	1.17
High carbon price					
Net present value of energy savings	$10,305.02	Net present value of energy savings	$2,791.74	Net present value of energy savings	$5,525.81
Net present value of costs	$4,392.52	Net present value of costs	$4,392.52	Net present value of costs	$4,392.52
BCR	2.35	BCR	0.64	BCR	1.26
Crimson 6 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value of energy savings	$11,345.45	Net present value of energy savings	$3,241.56	Net present value of energy savings	$6,175.34
Net present value of costs	$5,607.48	Net present value of costs	$5,607.48	Net present value of costs	$5,607.48
BCR	2.02	BCR	0.58	BCR	1.10
High carbon price					
Net present value of energy savings	$12,384.29	Net present value of energy savings	$3,355.04	Net present value of energy savings	$6,640.76
Net present value of costs	$5,607.48	Net present value of costs	$5,607.48	Net present value of costs	$5,607.48
BCR	2.21	BCR	0.60	BCR	1.18
Hickman 6 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value	$11,8	Net present value	$3,3	Net present value	$6,4

of energy savings	88.34	of energy savings	96.67	of energy savings	70.83
Net present value of costs	$4,485.98	Net present value of costs	$4,485.98	Net present value of costs	$4,485.98
BCR	2.65	BCR	0.76	BCR	1.44
High carbon price					
Net present value of energy savings	$12,976.89	Net present value of energy savings	$3,707.68	Net present value of energy savings	$6,958.53
Net present value of costs	$4,485.98	Net present value of costs	$4,392.52	Net present value of costs	$4,485.98
BCR	2.89	BCR	0.84	BCR	1.55

Kingston 7 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value of energy savings	$13,030.15	Net present value of energy savings	$3,722.90	Net present value of energy savings	$7,092.32
Net present value of costs	$11,121.50	Net present value of costs	$11,121.50	Net present value of costs	$11,121.50
BCR	1.17	BCR	0.33	BCR	0.64
High carbon price					
Net present value of energy savings	$14,223.24	Net present value of energy savings	$4,063.78	Net present value of energy savings	$7,626.85
Net present value of costs	$11,121.50	Net present value of costs	$11,121.50	Net present value of costs	$11,121.50
BCR	1.28	BCR	0.37	BCR	0.69
Crimson 7 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value of energy savings	$15,621.50	Net present value of energy savings	$4,235.66	Net present value of energy savings	$8,502.79
Net present value of costs	$17,663.55	Net present value of costs	$17,663.55	Net present value of costs	$17,663.55
BCR	0.88	BCR	0.24	BCR	0.48
High carbon price					
Net present value of energy savings	$17,051.87	Net present value of energy savings	$4,871.96	Net present value of energy savings	$9,143.63
Net present value	$17,6	Net present value	$17,6	Net present value	$17,6

of costs	63.55	of costs	63.55	of costs	63.55
BCR	0.97	BCR	0.28	BCR	0.52
Hickman 7 star					
Electric heating (100% efficiency)		Electric heating (350% efficiency)		Gas heating	
No carbon price					
Net present value of energy savings	$15,117.28	Net present value of energy savings	$4,319.22	Net present value of energy savings	$8,228.34
Net present value of costs	$7,570.09	Net present value of costs	$7,570.09	Net present value of costs	$7,570.09
BCR	2.00	BCR	0.57	BCR	1.09
High carbon price					
Net present value of energy savings	$16,501.47	Net present value of energy savings	$4,714.71	Net present value of energy savings	$8,848.50
Net present value of costs	$7,570.09	Net present value of costs	$7,570.09	Net present value of costs	$7,570.09
BCR	2.18	BCR	0.62	BCR	1.17