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A House Efficiency Investigation Using A Full Life Cycle Analysis and Measured Operational Data Through the ’10 House Living Labs’ Project

ENG470 Engineering Honours Thesis

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Declaration

This thesis is submitted to the School of Engineering and Information Technology, Murdoch University, as partial fulfilment of the requirements of ENG470 Engineering Honours Thesis, 2016

I, Luke Murphy, declare that the work presented herein is my own work, unless states otherwise and excluding references and appendices. The results contribute to the PhD research project ’10 House Living Labs’ undertaken by Christine Eon.

Signed _________________

Luke Murphy

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Abstract

The building industry currently accounts for approximately one fifth of the total greenhouse gas emissions in Australia. With the expected rise in population as well as the combination of smaller family sizes and the demand for larger more comfortable houses the impact of the building industry will continue to increase. Many different mandatory and voluntary rating tools have been developed around the world to ensure buildings move to become more sustainable, however studies have shown that these sustainable homes often underperform as they consume more energy than expected. Under the Nationwide House Energy Rating Scheme (NatHERS), Australia has targeted the operational energy reduction for heating and cooling. It has been found that there is a gap between the rating and the actual operational output of the houses as poor build quality, inaccuracy of the assessment tools and the occupants lack the knowledge on how to operate and maintain their homes efficiently all contributing to higher than expected operational energy. A broader outlook on sustainability outside of the operational energy demand of a house, Life cycle assessment tools are becoming increasingly more common. A life cycle assessment tool provides a complete evaluation of the carbon footprint in terms of the greenhouse gas emissions for the entire embodied and operational energy of a house which can be used in combination with the existing NatHERS to increase the understanding of sustainability in the Australian building industry. A life cycle assessment also has the potential to be used as a decision making tool to identify and influence the products or processes that would optimise the sustainability of the building.

This study includes monitoring the energy and water used in each home in addition to the photovoltaic solar production observed during the first year of the two year monitoring period for ten existing houses. The houses consist of both new six star rated homes as well as older retrofitted homes with different occupancies. The houses were all assessed with life cycle assessment software called eTool which measured the full lifecycle global warming impact of the existing houses. The operational data was then compared with the eTool prediction to investigate the house efficiency comparing the two ratings to identify specific areas of operational reduction improvements. Further analysis of the houses operational monitored data occurred via the process of an audit to further investigate how the occupant’s behaviours and house inefficiencies influence the performance of the house in terms of energy and water efficiency and whether there were any common trends identified among the houses.

The results of the study found that the eTool life cycle assessment provides an accurate representation of the actual energy and water usage based of the ten houses when compared with the 2015 measured values. The variations that did occur through the eTool assessment were identified further via the audits and were found to be associated with behaviour choices of the occupants, inefficiency with build quality, design or problems with technologies employed. Some technology problems encountered during the audit was that solar hot water systems were underperforming for some houses due to shading occurring during winter. An insight into the house inefficiencies was achieved by investigating the thermal performance of the building during the audit. The tool used was a thermal imaging camera. This identified that the major areas of heat gain were through missing insulation and unshaded east and west facing windows. From the life cycle assessment inefficiencies with solar photovoltaic production were detected at three of the houses due to the systems being shaded, dusty and located on a southern facing roof. The Life cycle assessment report also helps identify that the older houses which consist of lightweight construction have a lower embodied energy than the newer double brick houses. Interestingly the embodied energy of a retrofitted house with the old section being double brick and the new section being lightweight bulk insulated cladding has its highest impacting materials being brick and concrete. Another finding was that most of the houses had a higher portion of the solar production exported to the grid rather than utilised by the house which indicates that perhaps the PV systems are not being used to their full potential.

Glossary

LCA	Life Cycle Assessment
NatHERS	Nationwide House Energy Rating Scheme
HERS	House Energy Rating Scheme
NZeb	Nearly Zero Energy Building
BASIX	Building Sustainability Index
PV	Photovoltaic solar panels
HVAC	heating ventilation and air conditioning
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
kWh	Kilowatt Hours
LED	Light Emitting Diode
CFL	Compact Fluorescent Light
kL	Kilolitres
EPBD	Energy Performance of Buildings Directive
USA	United States of America
UK	United Kingdom
GBI	Green Building Initiative
CASBEE	Comprehensive Assessment System for Built Environment Efficiency

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1.0 Introduction

1.1 Background

In Australia the building sector accounts for approximately 20% of the energy and 23% of the total Australian greenhouse gas emissions (Lawania and Sarker 2015). While the building sector is one of the main contributors to climate change, buildings are considered as a “goldmine” for greenhouse gas mitigation due to the cost effective opportunities that can take place within the sector (Ürge-Vorsatz and Novikova 2008). It is anticipated that the projected population growth, the trend to smaller family sizes, and the desire for a more comfortable indoor environment and larger houses will increase the energy demands, and subsequent GHG emissions from the residential building sector (Wang, Chen and Ren 2011).

In the residential sector alone approximately 40% of the energy used in a typical home is for space heating and cooling throughout the year (Dong, Soebarto and Griffith 2015). Consequently residential building energy performance has been one of the major target areas of emission reduction schemes and regulations (Wang, Chen and Ren 2011). House energy rating schemes (HERS) around the world have been developed in an attempt to mitigate the amount of energy consumed in the building sector during the operation phase of the building (Daniel, Soebarto and Williamson 2015). In addition, governments around the world have introduced mandatory energy performance requirements to reduce levels of energy consumption and lower household carbon emissions (O’Leary et al. 2015), (Fesanghary, Asadi and Geem 2012).

These mandatory energy requirements have typically included the operational energy within a house. More specifically Australia’s Nationwide House Energy Rating Scheme is limited as it is restricted in rating a house based on the theoretical external heating and cooling requirements. Research has found that actual building energy performance varies greatly when compared to the theoretical models (O’Leary et al. 2016). A study done by the CSRIO (Ambrose and Syme 2015) investigates whether the built product meets the minimum specification of the NatHERS design rating of a house. They found the air tightness varied within the houses while 59% of the insulation was rated average or poor in quality. Mays and Castle (2014) explain that apart from the initial design phase, there is no assessment to ensure the build quality meets the energy rating which means there is no accountability for builders to deliver the 6 star rating. Similarly it can be shown that occupant behaviour can also be an important factor in the performance of a dwelling (O’Leary et al. 2016) (Ridley et al. 2014).

Operational energy is only a portion of the overall carbon footprint of a household. In Europe the Energy Performance of Buildings Directive (EPBD) target for all new buildings in the EU is to be 'Nearly Zero-Energy Buildings' from 2020 (Schimschar et al. 2011). The UK's target for all new homes to meet the requirements for a home to qualify as zero carbon is that it must: 1, reduce its energy demand through building material efficiency; 2, comply with any external emissions remaining after fabric performance is considered; and 3, reduce the remaining CO_2 emissions to zero by further reduction to process 1 and 2 or by investing in offsite carbon reduction projects or renewable energy (Zero Carbon Policy 2016).

As countries progress towards high energy performance homes that require low operational energy, the contribution of embodied energy in materials will become more important in relative terms, especially if an overall goal is to reduce the building's life cycle energy use (Thiel et al. 2013), (Himpe et al.2013). The life cycle analysis of a building can show quantitatively various types of environmental impacts, including energy consumption and CO_2 emissions of a building during its whole life cycle (Hong et al. 2014). An advantage of using LCA software is that it can provide a standardised method for comparing the relative sustainability of similar products or processes. It can also identify points in a product or process cycle where environmental impacts are relatively high and changes could be made to improve the sustainability of the overall system (Thiel et al. 2013).

1.2 Aim and Objectives

This study was conducted as a work package contributing to the PhD research project, '10 House Living Labs' conducted by Christine Moura Eon through the Curtin University's Sustainability Policy Institute and to be presented as part of ENG470 'Engineering Honours Thesis'. Christine's PhD research project is an investigation into the efficiency of 10 single detached homes in the Fremantle area through data monitoring across two years.

This present study for ENG470 thesis has the objectives to:

I. Conduct a full life cycle analysis of each house to further assess the sustainability of the building and to determine how a life cycle analysis tool can benefit the design by considering alternative products to reduce the operational and embodied carbon footprint of the home.

II. Investigate how occupant's behaviour influences the performance of the homes and identify energy efficient behaviours that will reduce the operational energy of the house.

III. identify any house inefficiencies due to the design of the house or build quality that may contribute to excess energy use or an uncomfortable home and provide some advice on how to further improve the performance of the home

IV. Recommend what is required to improve the sustainability of the housing market in Australia.

1.3 Limitations of the study

The ten houses used were self-selected samples that may not represent the entire Australian population.

Some of the houses in the study are retrofitted homes which haven't received any NatHERS thermal energy rating or have received a deemed to satisfy rating. This makes it difficult to compare the rated houses with the unrated houses as assumptions are required to be made on the heating and cooling requirements. To enhance the accuracy of the eTool operational assessment a NatHERS star rating can be carried out for the unrated houses.

The monitoring website used during the second year of the study is relatively slow to access, making it inconvenient for the occupants. In addition it would be beneficial to test alternative monitoring websites and equipment to further identify what is required for occupants to utilise this equipment to its best possible capabilities.

House B experienced a change in occupants for the second year of data monitoring which meant only nine behavioural change audits were able to be carried out instead of ten. The research will now however be able to compare the two types of occupants to further analyse the effects of the occupant's behaviour on the house performance.

To investigate the behaviour change further and to avoid the educated assumptions for high use behaviours, the study would benefit having more monitoring devices measuring the hot water system, air conditioners and gas heaters independently to obtain a more accurate breakdown of the energy used throughout the homes.

2.0 Literature Review

2.1 Sustainable Housing

The definition of sustainability remains broad when it comes to the housing industry. For example, sustainability was labelled with different terms such as “low carbon,” “zero energy,” “high performance” and most commonly “green” (Yang and Yang 2014). Housing sustainability should not, only cover the aspect of energy efficiency, but include resource usage, natural and socio-cultural systems, growth and economic demands and the lifestyle of current generations (Yang and Yang 2014). After the adoption of the 17 sustainable development goals in 2015 and in particular goal 11 on sustainable cities and communities, further focus will be placed on how it will impact mainstream housing policy to ensure safe and affordable housing, upgrading slum settlements and improving urban planning and management (Smets and Lindert 2016) ("Goal 11: Sustainable Cities And Communities" 2016). “Sustainable development cannot be achieved without significantly transforming the way we build and manage our urban spaces” ("Goal 11: Sustainable Cities and Communities" 2016). This statement emphasises the importance of improving the current standard of building and operating houses as the world population continues to grow and resources become scarce.

An article by Griggs et al. (2014) identifies that a set goal and target for each sustainable development goal is required for it to be achieved. The ’10 house living labs’ study provides solid data into the performance of ten residential dwellings, including information on the embodied energy of each dwelling. The comparison between the houses from the life cycle analysis can help identify unsustainable methods and materials and whether it has any impact on the performance of the houses, as well as some insight into potential residential targets that could be realistically achieved.

Despite the potential benefits and technological viability, voluntary uptake of sustainable housing is still in its infancy in Australia and is mostly driven by motives of experimentation, showcasing and marketing (Yang and Yang 2014), To get the most bang for the buck, cash outlays in green building should target low-hanging fruits such as consideration into orientation, shading, sealing the home and insulation (Schmidt 2008). An additional aspect of a sustainable home is ensuring that the occupant behaviours are continuously trying to reduce the operational energy of a home. The occupant behaviour choices are important to reduce the likelihood of the rebound energy effect where savings in one area may lead to a demand for a more comfortable lifestyle in another area, which in turn offsets the original efficiency improvement (Lin and Liu 2015).

2.2 Mandatory Rating Tools

House energy rating schemes around the world have been developed in an attempt to mitigate the amount of energy consumed in the building sector during the operation phase of the building (Daniel, Soebarto and Williamson 2015). An overall objective of energy policy in buildings is to save energy consumption without compromising comfort, health and productivity levels so that a dwelling consumes less energy while providing equal or improved building services (Pérez-Lombard et al. 2009.) An investigation into these mandatory tools employed by government policy focus heavily on the demand for space heating and cooling rating prior to 2010 (Schimschar et al. 2011).

House Energy Rating Schemes have been developed with consideration given to regional conditions and climates (Hurst 2012). Australia's Nationwide Household Energy Rating Scheme simulates the thermal performance of the building envelope and, based on predicted heating and cooling loads to maintain the prescribed 'comfort range', producing a star rating from 0 to 10 (Daniel, Soebarto and Williamson 2015). A star rating of 10 means it requires little heating and cooling and a star rating of 0 means it requires a large amount of heating and cooling.

The European standard requires an Energy Performance Certificate to determine the expected primary energy consumption of buildings. The second stage is for a second Energy Performance Certificate to be produced to determine the actual performance of the house (Pérez-Lombard et al. 2009). Each country within Europe can have its own performance certificate if it is recognised by the member state. Sweden, Netherlands, Austria, Ireland and Germany use their respective schemes BBR18, Bouwbesluit, IOB- Richtlinie, Part L and EnEV to determine their energy rating towards the thermal envelope requirements as well as energy use within the house with some states in America such as California having its own operational energy rating schemes CALGreen Code (GBPN 2013).

Within Australia, the NSW government adopted the Building Sustainability Index (BASIX), being the first state in Australia to develop its own mandatory sustainability index. BASIX covers the thermal performance of the building as well as water and energy consumption reductions compared to the state averages (GBPN 2013). A Basix certificate is required for any new home or alterations in excess of 50 000 dollars to an existing home (Department of Planning. 2011)

The minimised energy demand and air tightness of a passive house and the low energy buildings have provided in the past a step forward to the energy efficiency goal and the nearly zero energy building (Connolly and Prothero, 2008). However, some scholars criticised that the energy efficiency rating systems merely focus on operational carbon, but not on the emissions generated throughout the buildings life cycle (Wong et al. 2015)

The Energy Performance of Buildings Directive (EPBD) recast 2010/31/EU and the regulation 244/2012 initiated an effort in reducing the energy consumption and increasing the share of renewable energy sources in the building sector. Towards the goal of 2020, all European Union (EU) member states strive to meet the obligation of the complete definition and requirements of the nearly zero energy buildings (nZEB) on a national level Chastas, Theodosiou and Bikas (2016). In a literature review by (Chastas, Theodosiou and Bikas 2016), significant gaps are identified in the definition of an NzEB and its methodological framework. With the reduction of operational energy in nearly zero energy buildings contributing to an increased proportion in embodied energy throughout the entire lifecycle of the building.

With the International movement in legislation being towards reducing operational energy in buildings, steps need to be taken to ensure the embodied energy used throughout the lifecycle of a building doesn't replace the reduction in operational energy. By employing a life cycle assessment tool in association with the Australian mandatory HERS rating, the '10 House Living Labs' study can investigate the portion of operational and embodied energy of the houses to ensure a continuous energy reduction for varying housing typologies.

2.3 Voluntary Rating Tools

There are mandatory rating tools that governments employ to reduce the operational energy required by the houses and there are also voluntary rating tools used by planners, architects and builders to help achieve an increased sustainability certification and reduce greenhouse gases (El shenawy and Zmeureanu 2013). Some of the tools widely applied to assess the sustainability of urban projects include BREEAM-Community, LEED-ND, CASBEE-UD, SBTool2012 and GBI for Township (Charoenkit and Kumar 2014). These tools are primarily used to achieve a higher certification and level of sustainability. As can be seen in table 1; the criteria these certifications are assessed against are a much wider range than the mandatory certification which is based on operational energy reductions.

Table 1: Voluntary sustainability assessment tools and the aspects they cover, Table from Charoenkit and Kumar 2014)

	Criteria	Rating
BREEAM	Community Transportation Land use Social and economics Innovation	Outstanding (≥85%) Excellent (≥70%) Very good (≥55%) Good (≥40%) Pass (≥25%)

	Governance Resources and energy	Unclassified (<25%)
LEED	Smart growth Neighbourhood design Green building Innovation Regional priority	Platinum (80–100) Gold (60–79) Silver (50–59) Certified (40–49)
CASBEE	Global warming effect Natural environment Serviced Functions Contribution to community Environmental impact Social infrastructure Management of Environment	Excellent (<0.5) Very good (0.5–1.0) Good (1.0–1.5) Fairly poor (1.5–3.0) Poor (≥3)
SBTool2012	Location Redevelopment Energy and resource consumption Environmental loading Indoor quality Service Quality Social and Cultural aspects Cost	Best practice (5) Good practice (3) Minimum (0) Negative (−1)
GBI	Climate Energy and Water Environment Community Transportation Building and Resources Innovation	Platinum (≥86) Gold (76–85) Silver (66–75) Certified (50–65)

Life cycle assessment (LCA) tools have been utilised widely to assess the life cycle GHG emissions and embodied energy consumption of the infrastructure industries (Lawania and Sarker 2015). LCA has been employed to complement the mandatory energy ratings in sustainable housing projects and have begun to be integrated into other voluntary assessments such as LEED and BREEAM, where extra credits can be obtained from using this assessment. ("Whole Building Life Cycle Assessment | U.S. Green Building Council" 2016) ("Scoring LCA Green Building Credits In BREEAM, LEED and CEEQUAL" 2016). Some LCA software currently existing in the market to assess the sustainability of buildings includes BEES, ATHENA, GaBi Build-it, and SimaPro. They take into consideration the full life cycle of the materials including the manufacture, transportation, production, operation, maintenance and demolition of the project and can identify and make recommendations on how to reduce the carbon footprint of the building. Zabalza, Ignacio, and Sabina Scarpellini (2009) found there are some gaps in LCA's regarding environmental indicators, the presentation of the results to users and adapting LCA to various purposes such as early design phases. There is also difficulty in defining boundaries as many buildings undergo various changes throughout its life.

Even though there are various LCA assessment tools available, eTool was chosen as it incorporates all the life cycle impacting factors mentioned above, is specific to the chosen building types and is developed by a local company here in Perth, Western Australia.

Anda and Ploumis (2015) analyse and compare some techno-economic assessment tools that can be used to identify and select alternative infrastructure options for water cycle systems, energy efficiency and generation at both the city and individual dwelling level. The investigation found that among the tools investigated Austodesk Revit and Ecotect were the only tools that could incorporate electricity, thermal, water supply and wastewater management together. In addition the tools are mainly used for design purposes, not for recommended solutions. Given the scope of the '10 House Living Labs Project, the information available is not sufficient to warrant using individual specialised tools for assessing the 10 houses.

2.4 Behaviour Impacting Energy use

Occupant Behaviour has been identified as the principal cause of monitored energy use variation between identical homes, as well as between the expected energy model and the actual use (O'Leary et al. 2016). Hargreaves (2011) revealed that conventional accounts of behaviour change, with their focus on individuals' cognitive states and contextual 'barriers', are too narrow to capture the full range of what is involved in behaviour change interventions and may need to be abandoned, instead greater research and policy attention should be paid to generate more sustainable practices. This study uses the concept of a Living Lab where the occupants are placed in a social space to allow for effective impact evaluation to change their existing behaviours and to become creative innovators for new emerging ideas (Rosado et al. 2014).

A study done by O'Leary et al. (2015) reviews and evaluates using household metered energy data for rating building thermal efficiency for either very high or very low star rated buildings. The study found that behaviour and other energy demands in the house were a dominant factor in determining the overall energy demand of the house, not just space heating and cooling. The two data sets being collected 12 years apart and the distinct difference of having a 7 star house and an estimated 3 star rated house could affect the study as technology advances and societal attitudes may have contributed to occupant behaviours changing significantly over the 12 years.

The second study by (O'Leary et al. 2016) compares the measured energy consumption for heating and cooling against the NatHERS modelling. The results show that while a higher star rating house typically uses less energy than the lower rated house, there is a significant difference in energy demand across each data set due to occupancy factors. This will be further investigated in the ’10 House Living Labs’ study as these studies all have similar components to the ’10 House Living Labs Study’ with the house NatHERS model rating comparison with the measured data. The living labs study however measures not only the energy of the house, but water use, solar production and the solar energy exported back to the grid. The addition of a full lifecycle analysis of each house helps to gain an additional understanding of the embodied and operational energy of each house.

Both the studies O’Leary et al. (2015) and O’Leary et al. (2016) focus primarily on behaviour change associated with operational energy. This study investigates the possibilities of using a life cycle analysis tool to impact the behaviours by providing the capability of choosing more environmentally friendly options in the design phase that can lead to less embodied energy being spent during construction as well as in the operational phase of the building. This tool can help visualise the impacts certain materials or decisions have on the performance of the building through its lifecycle, this in turn can lead to improved behaviour decisions.

2.5 Photovoltaic performance modelling

There are 1.2 million Photovoltaic (PV) systems in Australia and less than 1% of these have any effective form of monitoring or ability to determine the actual performance of the system. The rapid growth of distributed small scale PV systems has increased the need for tools that can undertake reliable real time monitoring of system performance with the capability to detect and diagnose underperformance at the earliest possible stage (Department of Industry and Science). Solar analytics which is a PV monitoring tool offered by Suntech is an algorithm to improve and test the performance of a PV system whether it be residential or commercial.

Given the need to effectively monitor photovoltaic system performance this study can use the operational production obtained from the monitoring equipment and compare the data with the eTool prediction for solar production. The details provided for the photovoltaic system sizes and the average daily radiation can be entered into eTool to calculate the expected output of the system. By comparing the eTool prediction against the measured data, two things can be investigated; whether the eTool assumption for solar energy production is accurate and if it is accurate then it can help investigate the status of the system’s performance.

2.6 Retrofitted homes

The mandatory requirement for new homes to meet the minimum NatHERS rating in Australia has no impact on already existing homes which are not required to meet any requirements, unless a renovation that includes an extension is being completed. Even then the extension is the only section of the house that is required to meet the minimum rating. Cecily and Horne (2011) states that significant improvements to existing stock and changes to how it is inhabited are required to improve the environmental performance of residential dwellings. It is also suggested that future policy and programs need to look beyond attitudes and behaviour and focus more on the social practices in daily life.

The 'Ten House Living Labs' study includes retrofitted homes; however the retrofits in the older homes are done by environmental conscious homeowners to reduce the carbon footprint of the homes by investing in 'green technology' as well as increasing the thermal performance of the home by improving the insulation and air tightness. For some homeowners 'green technology' isn't adopted due to it having no economic benefit for them. Cecily and Horne (2011) recommend further consideration in research, policy and programs needs to be given to fundamental conventions and practices embedded in daily routines to encourage 'practice' change rather than 'behaviour' change.

International initiatives, such as the Clinton Climate Initiative's Energy Efficiency Building Retrofit Program in the USA, the 'Great British Refurb' campaign in the UK, the Canadian ecoEnergy Efficiency Incentive for Buildings and the Green Loans program launched in Australia, demonstrate the growing policy interest in the retrofitting of housing (Cecily and Horne 2011).

This study includes an existing housing stock which consists of recently built houses in addition to older retrofitted homes. Even though there is no mandatory requirement to meet a minimum thermal performance rating for existing houses, this paper will investigate efficiency methods and technologies employed by the occupants to reduce the operational energy requirements of an existing house.

2.7 Local Sustainable Housing Examples Using LCA Studies

Two local residential housing projects in the Perth metropolitan area have demonstrated a high level of sustainable practice. In addition to the building Code of Australia's mandatory NatHERS thermal performance rating, the buildings have gone to the next level by employing eTool to assess their environmental impact and overall sustainability.

2.7.1 Josh's house

Josh's House Project is a project showcasing the benefits of sustainable housing to the community as part of a research program "high performance housing" undertaken by Curtin University's Sustainability Policy Institute through the Cooperative Research Centre (CRC) for low carbon Living. The project set out to prove that a sustainable home can be built at a comparable cost and timeframe to regular houses (“Josh’s House” 2016).

The project resulted in two houses being built on a subdivided block with both houses achieving a 10 star NatHERS certificate. By understanding that heating and cooling typically accounts for 40% of the total operational energy of a house, other measures including the embodied energy and water efficiency aren’t accounted for by NatHERS. eTool was identified as an assessment tool which would take these factors into consideration. The house achieved a saving of 23% in the embodied carbon reduction and a 111% operational carbon reduction compared with the residential benchmark.

2.7.2 The Siding

For The Siding the goal was to create affordable medium density housing in an inner city area with a primary focus on sustainability ("Energy | The Green Swing" 2016). The housing includes two residential town houses; four, three bedrooms apartments; and one, three bedroom apartment in a complex with a shared communal space and garden.

The energy rating that was achieved for the apartments ranged between nine and ten stars with the results showcasing much higher ratings than the minimum NatHERS standard of six stars. As described above an eTool assessment was also carried out to rate the dwellings in terms of the embodied and operational energy of the development. The LCA result was an overall saving of 80% compared to the benchmark which consisted of savings of 60% and 91% for the embodied and operational carbon respectively. This result indicates that the homes will need little to no heating and cooling as well as have a relatively low embodied energy compared to the average dwelling and have low additional operational energy requirements for other appliances within the dwellings.

These high standard sustainability projects have used both NatHERS and eTool to assess their environmental impact. With the adoption of eTool it can be seen that savings can be made to both the operational and embodied energy by choosing sustainable materials as well as good design. The ’10 House Living Labs’ project uses the monitored energy and water data to determine the houses’ actual performance. By completing an LCA for each of the ten houses the predicted operational energy can be compared with the actual usage to determine the accuracy of the rating tool and whether the house is operated as it has been intended.

3.0 Methodology

3.1 '10 House Living Labs' Selection Process

An advertisement went out to the City of Fremantle asking for participants willing to be part of a two year monitoring study where their energy, water and gas usage would be monitored for a two year period with behaviour intervention techniques being implemented after the first year of data is collected. The participants received monitoring equipment for their houses that monitored their energy and water usage. This ensured the ten houses that were selected for the project were all from the City of Fremantle, in Western Australia. Noting that the sample was selected based on households that were engaged in reducing their energy and water consumption as the benefit of participating in the study was to receive monitoring equipment to measure the energy and water consumption.

The chosen houses comprised of single detached dwellings of low density with varying housing typologies and occupation profiles (Table 2). Each dwelling is either at or above the mandatory housing energy rating scheme requirement or possesses technologies or design components making them more 'sustainable' than the average Australian home. These features are summarised in Table 2. Three houses (L, M and O) have been built to meet the Australian building code requirements in that all homes built from 2012 must achieve a minimum six star NatHERS rating. House P has the retrofit addition section of the house meeting this minimum rating of six stars. House F is classified as deemed-to-satisfy, which means it is not rated by the accurate software, however it follows prescribed design aspects and materials given by the national construction code (NCC). Two houses (C and E) are homes which have been retrofitted with insulation, photovoltaic systems (PV) and solar hot water systems. Three houses are considered as high performance homes as their NatHERS rating is above seven stars. Nine of the ten houses selected have a photovoltaic system, eight have a solar hot water system and seven have rainwater tanks.

Table 2: House Typology (Source: Christine Eon et al. 2016 unpublished paper.)

House	Year built	Occupancy	Habitable area (m^2)	Design	Energy/Water systems	NatHERS code/description
B	2009	4 young adults	185	Double brick walls with reflective insulation; Concrete slab; R3 ceiling insulation; R1.5 roof insulation; North facing living room.	1kW PV system; Solar hot water system with gas booster	8.5 Stars
C	1950 - renovations in 2011	2 adults and 2 children	106	Timber frame walls with R2 insulation; Ceiling R4 insulation; Suspended timber floor with R1.5 insulation; Low-e glazing to North and West; North facing living room.	1.5kW PV system Solar hot water with electricity booster	Retrofitted
E	1899 renovations in 2001	2 adults	120	Limestone and double brick; Suspended timber floor and concrete slab; Ceiling R3.5 insulation; Roof R1.5 insulation; East facing living room.	1.5kW PV system; Solar hot water with electric booster	Retrofitted
F	1920 renovations in 2014	2 adults and 2 children	183	Double brick, timber frame walls with R3.5 insulation; Concrete and suspended timber floor; Ceiling R3 insulation; Roof R1.5 insulation; Low-e glazing; North facing living room	1.5kW PV system; Solar hot water with gas booster	Deemed-to-Satisfy
G	2011	2 adults and 1 young adult	195	Rammed earth, insulated panel walls R2.5 insulation; Concrete slab; Ceiling R3 insulation; Roof R2.5 insulation; Low-e glazing; North orientation	2kW PV system; Instantaneous gas water; heater	7 Stars
H	2011	2 adults and 2 children	238	Rammed earth, double brick with R2.5 insulation Concrete slab; Ceiling R3 insulation; Roof R2.5 insulation; Low-e to East and West; North facing living room	2.28 kW PV system; Solar hot water with electric booster	8 Stars
L	2013	2 retired and 1 young adult	218	Double brick walls; Concrete slab; Ceiling R4 insulation; West facing living room	Solar hot water; with electric booster	6 Stars
M	2013	1 adult and 3 teenagers	147	Double brick walls; Concrete slab; Ceiling R3 insulation; North facing living room	2.5kW PV system; Solar hot water with gas booster	6 Stars
O	2013	2 adults	154	Double brick walls; Concrete slab; Ceiling R4 insulation; North facing living room	2kW PV system; Solar hot water with gas booster	6 Stars
P	1901 renovations in 2014	2 adults and 3 children	162	Timber frame walls with R2 insulation; Concrete and suspended timber floor; Roof R4.5 insulation; Low-e glazing to West and double glazing to South; South orientation with North facing clerestory	4kW PV system; Instantaneous gas water heater	6 Stars

3.2 Monitoring Equipment and data Collection

Monitoring equipment was installed in each of the participant's houses in order to measure the grid electricity and gas consumption, mains water consumption as well as the internal temperature of the living rooms in each of the houses. The photovoltaic energy generation was measured in the nine houses that possess a solar PV system. Rainwater was also recorded for the houses that owned a rainwater tank. Table 3 shows a more detailed description of what was monitored for each house.

The monitoring equipment used (Table 4) consists of multiple sensors that are coupled to the existing meters and transmit electric pulses to a data logger which then collects the data at 15 minute intervals. The data is transferred via csv files to the researchers remotely through a 2G wireless connection. The exception to this is house G where the gas meter is located well away from the house, so a connection between the driveway and the data logger was not feasible. In house G the data collection for gas consumption was recorded on a local data logger Onset Hobo UX90 512K and downloaded manually once per month on site.

As mentioned above, the total photovoltaic energy generation is measured via a data logger. To obtain the breakdown of solar energy utilised and exported, electricity bills were requested for the nine houses with solar PV installed at the end of each year which separates the solar energy utilised to what is exported back to the grid. In addition the external temperature was collected from a Vaisala WXT520 weather station belonging to a separate research house monitoring project located in Fremantle. This information was applied to all the houses.

Table 3 Data that was monitored for each house

House	PV	RW	Gas	Water	Temperature
B	X	X	X	X	X
C	X			X	X
E	X	X	X	X	X
F	X	X	X	X	X
G	X	X	X	X	X
H	X	X	X	X	X
L			X	X	X
M	X	X	X	X	X
O	X	X	X	X	X
P	X		X	X	X

Table 4: Monitoring equipment used for each house (Source: Christine Eon et al. 2016 unpublished paper.)

Parameters monitored	Meters & Sensors	Data logger
Gas	Ampy 750 & pulse kit for 750 meter	Schneider Electric COM'X 200
Grid electricity	Schneider Electric iEM3110	
Photovoltaic generation	Latronics kWh	
Internal temperature	Kimo TM110	
Mains water	20mm Elster V100 & MEB7454 'T' probe/ Actaris TD8 & Cyble sensor 2W K=1	
Rainwater	20mm Elster V100 & MEB7454 'T' probe	

3.3 Site Audit & Behavioural Influence Consultations

Part of the '10 House Living Labs' study includes the behavioural change component where it is understood that the behaviour of the occupants have a major influence on the energy consumption of houses being of a similar thermal performance rating. To comprehend this concept the first year of monitoring was used as the data gathering phase where the occupants knew the data was being gathered for their electricity, gas and mains water usage; however they had no access to this information other than their usual utility energy and water bills. There were no recommendations for reducing energy, gas or water in the first year of monitoring for this study. At the end of the first year there was a behaviour change audit where the results were gathered and analysed to produce a set of graphs to investigate any trends that lead to any particular behaviour causing electricity, gas or water to be used. Examples of some of the graphs presented to the occupants are seen in Figure 1, 2 and 3.

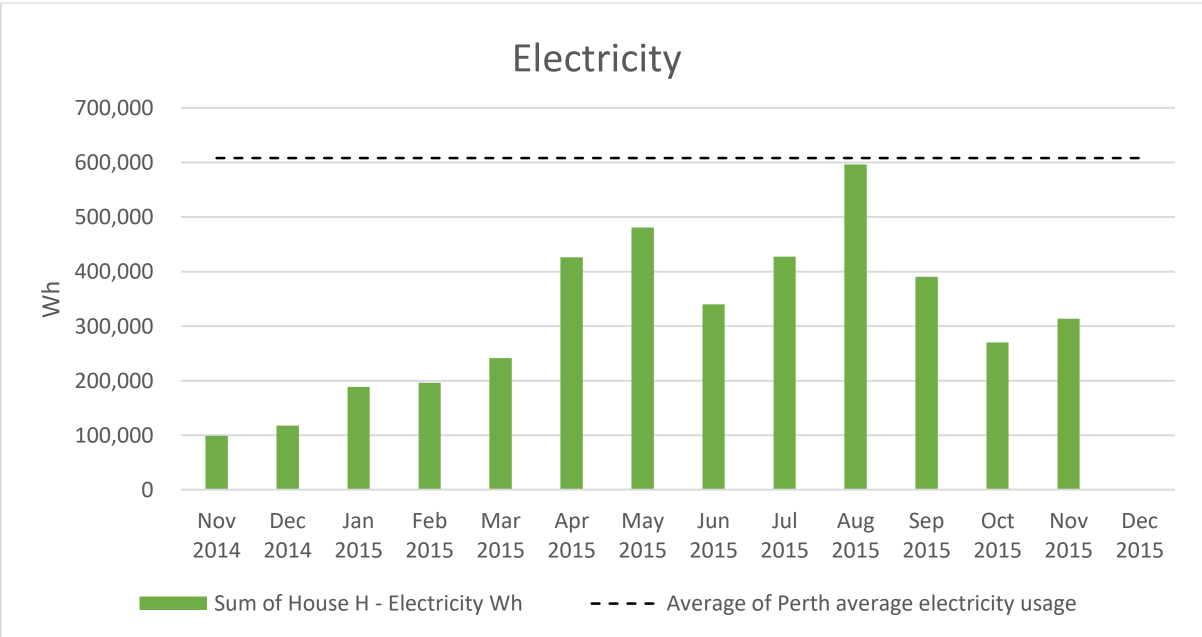


Figure 1: House H Energy consumption throughout the year (Source: Christine Eon 2015 audit report
***Note: data collection began in November 2014**

Figure 1 shows that house H has relatively low mains energy consumption in summer, but the electricity consumption in winter is higher. This is typical of a house with Photovoltaic solar production as you can see in Figure 2 the solar production is much less in winter.

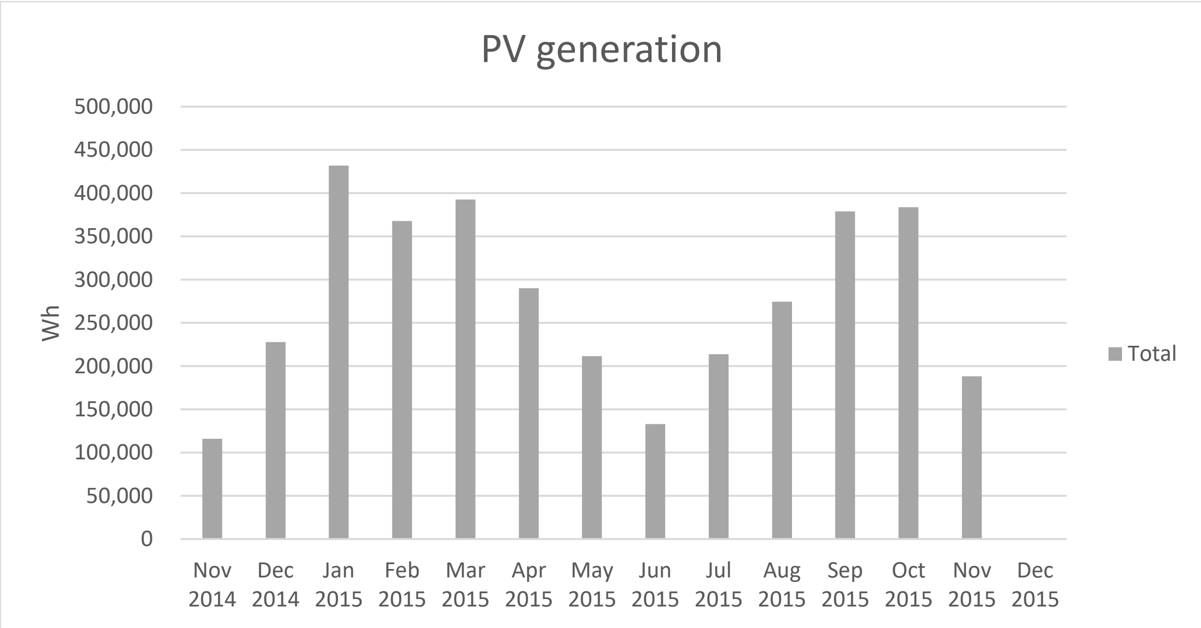


Figure 2: House H PV generation for year 1 (Source: Christine Eon 2015 audit report)

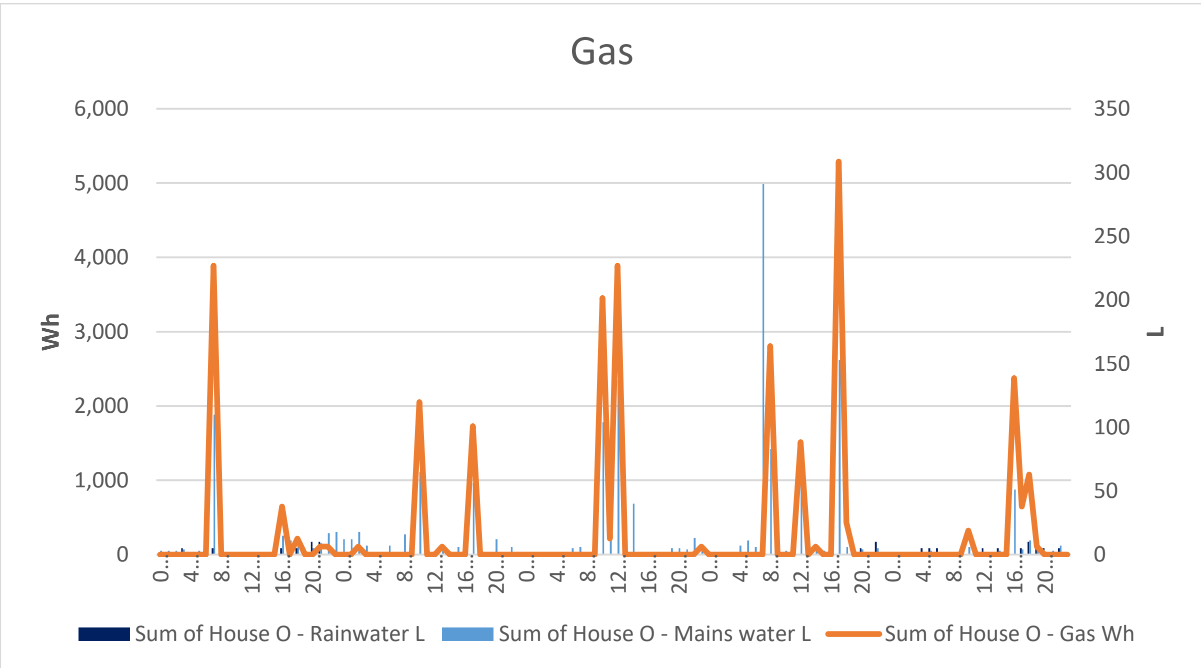


Figure 3: House O Gas usage in correlation with mains water use. (Source: Christine Eon 2015 audit report)

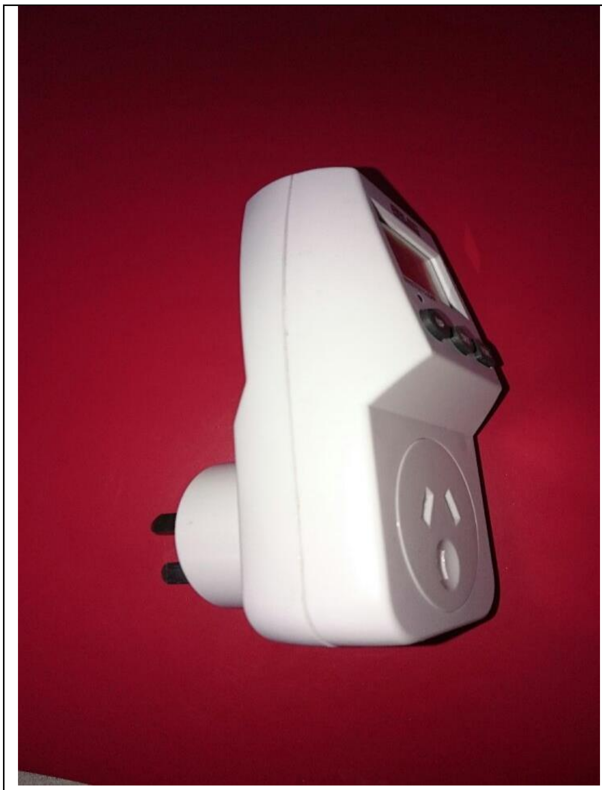
Figure 3 was shown to house O to explain the relationship between gas usage and the length of showers, this graph would inform the occupant that by reducing the shower time, they would not only save water but save on gas costs.

3.4 Summer Audit

To avoid unnecessary disruptions to the occupants daily lives the first site audit and summer behavioural consultation was carried out in one visit. A walk-through audit was undertaken during this visit to initially; collect detailed information of materials and appliances (seen in appendix B) used in the house that can contribute to completing the life cycle assessment component of the study; secondly, to investigate and discuss with the occupants any potential areas to improve the thermal performance of the house, for instance shading windows that receive direct sunlight and fixing any areas that allow heat gain or loss including missing insulation detected through the use of a thermal imaging camera, (Testo 870)shown in figure F in table 5. The final purpose of the walk-through audit was to identify and assess the energy usage and the efficiency of appliances in both the active and stand-by mode to investigate if there is any energy savings that can be made by switching the appliance off at the wall when not in use or replacing inefficient appliances. To measure the stand-by power the ARLEC energy cost meter PC222 was used which is shown as figure C and D in table 5.

Table 5: Examples of audit efficiency tests equipment (images taken by Luke Murphy)

 A. Energy Star Rating for appliances	 B. Water Star rating for appliances



C. Energy meter calculating device

D. Energy Measuring device in use

E. Specification plate found on devices

F. Thermal imaging Camera

An interview was conducted with each household during the first audit to get some background information of the households' views on sustainability and reducing their carbon footprint from reduced energy and water usage. The questions were:

- Who Lives in this House?
- Why did you decide to participate in this project?
- How important is it for you to reduce your greenhouse gas emissions?
- How important is it for you to reduce your energy consumption?
- How important is it for you to reduce your water consumption?
- How important is it for you to live in a comfortable home?
- How do you think people view reducing their greenhouse gas emissions?
- Is that how it is in your local community

- Do you think more people think it is important to reduce their greenhouse gas emissions now compared to one year ago?
- Is there support to reduce greenhouse gas emissions in your community?
- Is there support to reduce your greenhouse gas emissions in your household?
- Have you tried reducing your greenhouse gas emissions in the past?
- Did you encounter any barriers with this?
- What facilitated making changes?

The interview answers from the first summer audit for each house can be found in appendix C.

The last section of the first house visit was a garden consultation by Western Australia's ABC Gardening Australia TV presenter Josh Byrne where Josh offered his knowledge on caring for the existing plants in the garden, water savvy irrigation advice and appropriate native species that would thrive in certain areas.

Following the visit a recommendation summary report was completed for each household reiterating the areas for improving energy, water and gas usage that would lead to the biggest savings some key findings are outlined in section 5.2 of this report..

3.5 Winter Audit

A separate audit was carried out for each house in July 2016 to gauge the houses progress during the second year of monitoring and if any of the recommendations put forward had been carried out. Graphs were compiled focussing on high winter usage and tips to maintain the energy and water saving while staying warm in winter.

Comparable to the summer audit, an interview was carried out, this time focussing more on how the occupants have utilised the resources available to them and to find out if their views on energy and water conservation has changed in any way. The questions asked to each household were:

- Since the last visit, have you made any changes to your routine?
- Why did you make these specific changes/ Why not?
- Are you finding anything particularly difficult? Why
- Has anything helped you make these changes?
- Are your kids/ rest of the family participating?
- How often are you logging into the website?
- How useful are you finding the reports?
- Last time we talked about your views on energy and water conservation and on whether you found it important. Do you still think of it the same way after the last 6 months?
- Are you more conscious of your energy and water usage on a daily basis? Why do you think that is?

The results of the winter audit can be seen in appendix D.

After the interview similar to the summer audit, a walkthrough of the house occurred identifying any areas where heat transfer could be detected via the thermal imaging camera. The hot water systems were also looked at if accessible to ensure the temperature settings were correct and areas that would benefit insulation were discussed with the homeowners.

3.6 Goal Setting

At the end of the first audit, each house was provided with a chance to reflect upon their performance over the first twelve months. Specific areas and behaviours were discussed for where they could improve and based on these the occupants of the house were encouraged to set a target reduction goal they would aim to achieve to reduce their energy, water and gas usage over the coming twelve months.

3.7 Monitoring Website

After the first 12 months of the study the occupants have access to a monitoring website that presents the electricity, water and gas usage in a graph during the second year of monitoring so that they can get more frequent feedback. Figure 4 is a screenshot of the monitoring website showing the functionality. Each house can be individually viewed so that high energy use can be picked up immediately which could influence a change in behaviour. The website also allows a comparison between houses of similar ratings to allow the occupants a chance to see how they compare with each other.

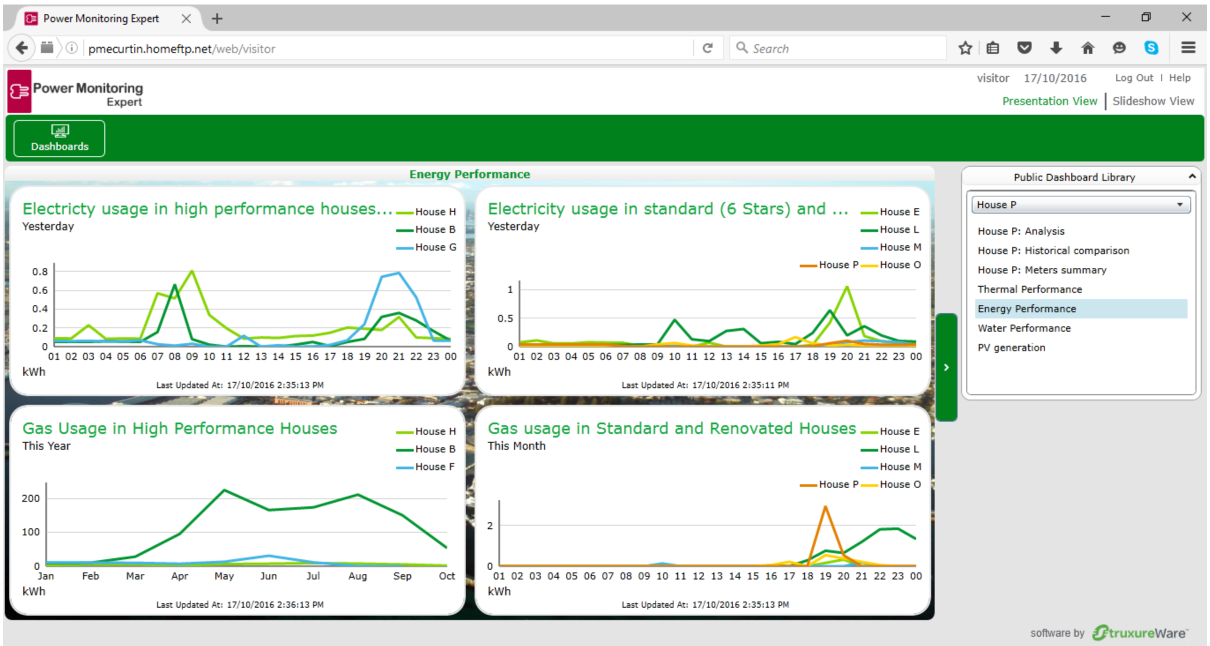


Figure 4 Monitoring website accessed by occupants during the second year of the study

3.8 eTool Training

eTool training was required prior to beginning the Lifecycle assessment to understand the program's capabilities and the processes involved to be able to carry out the life cycle analysis of each residential dwelling. The training was completed at the Perth eTool office over two days with the co-founder of eTool Richard Haynes. During the training, sample projects are created to understand the software and help guide the student through to certification level. The training includes setting up a process to obtain the quantities of each material from the project and entering that data into the eTool software through existing templates or creating a new template. During the training the functions are explained which allow recommendations to be made to reduce both the embodied and operational carbon footprint of the building in the design phase to identify useful and cost effective changes. Upon the completion of the training, an exam is carried out where a certificate of attendance is awarded if the exam is passed.

3.9 3D modelling

To get an accurate take-off for the materials for each individual dwelling almost any 3D modelling software can be used, for this project Google Sketch-up was chosen as it was recommended by personnel from eTool and it was found to be relatively quick and easy to learn.

The models use the dimensions from the house plans which were obtained from the homeowners at the beginning of the project to get the most accurate model and material take-off. Each specific structure was set to have its own layer that was able to be selected to display the area of each structure individually. This was an effective way to determine the areas of structures with multiple sections, for example the walls, floors, windows and doors of the buildings. Having layers also allow changes in thickness of walls and floor covering materials to easily distinguish between.

Appendix A shows a view of each 3D model and examples of some of the layers used to get the material quantities off-take that was collected and inputted into an Excel spreadsheet that includes all of the templates and inputs for the eTool program that can be found in appendix B.

3.10 eTool Reports and Results

From the notes and house plans obtained from each homeowner, the material gathered from the audit and the data collected from the 3D model, there was enough information to complete the life cycle analysis (LCA) through the eTool software. Each quantity of material entered in Excel from the material take-off was used to find or make a new template in eTool to build the complete dwelling LCA. Using the building materials and the Perth average appliance, energy and water usage the software is able to predict the embodied and operational energy of the building over its lifetime.

Three scenarios were created for each dwelling so that a comparison was made for the '10 House Living Labs' study. Scenario one predicted the carbon footprint of the operational usage for each house based on the average water, electricity and gas usage for the average occupancy of a dwelling with that particular number of bedrooms. Scenario two used the embodied energy from the actual appliances used in that particular house, the average number of occupants and the real-time data to determine the measured carbon footprint of the house. The third scenario was created to conduct a comparison on the embodied and operational carbon footprint and energy usage to be made per occupant. The electricity, water, and gas usage was standardised to be for the number of occupants eTool predicted for the dwelling. The embodied and operational energy were divided by the occupants and then multiplied by the eTool predicted occupants to get the standardised value. There was one value that wasn't standardised which was the solar production because the amount of solar generated isn't dependant on occupancy. This standardised scenario was later discarded due to the embodied energy, solar production, refrigeration and air conditioning being independent of occupancy however the results can still found in appendix F.

The eTool predicted scenario for each house was certified by a member of eTool to validate and ensure the LCA was carried out accurately and was an appropriate representation of each house. The Material offtakes for each house has been included in appendix B to provide transparency for the results.

Each house was compared with an eTool pre designed benchmark for an average Australian Standard and International Standard detached dwelling where eTool has created an average of 10 dwellings as if each has 3 bedrooms.

Table 6: Summary of eTool benchmarks (produced by Luke Murphy)

	International Residential Benchmark Weighted (x10 Dwellings)	AU Res Ave 2013 Code Compl CZ 5 (10 dwellings)
Total Dwellings	10	10
Total Bedrooms	30	30
Total Occupants	25.2	23.7
Total heating and cooling area	210	195
Energy Use	International Operational Benchmark	Res average (AUS) op & Em
Water Usage	169L/person/day (excl gardens)	160 L/p/day (excl gardens)

Water Treatment	169L/p/d	160 L/p/day
Energy Production	0	0

The results from the eTool reports were used to generate a series of graphs to compare the dwellings with one another in terms of their operational and embodied carbon requirements to determine the sustainability of each home. In addition the electricity and gas were compared to identify any houses that could target any areas to reduce the overall operational energy of the house.

4.0 Life Cycle Analysis

4.1 Introduction into carbon life cycle analysis (eTool)

The results from the life cycle analysis provide a measurement of the operational energy efficiency and the embodied energy consumed in building and maintaining each house. This gives a better understanding of the overall sustainability through the entire life of the dwelling, if the average Perth occupant lived in the dwelling.

The typical use of eTool is in the design phase of a development so that different options can be measured and explored to reduce the embodied or operational energy by using different technologies, materials or appliances. The life cycle analysis completed for this project was for already built new houses as well as retrofitted older homes. A benefit of this project is that the real life operating data can be compared with the expected data from eTool so a comparison can be made between the expected and actual operational energy used. Studies assuming a 40 to 50 year life span found that the use phase, or operational energy, contributes anywhere from 52% to 82% of the total life cycle energy consumption of a building (Thiel et al. 2013). The results from the eTool LCA of the 10 houses and the international and Australian benchmarks show the operational energy component contributes to an average of 48% of the total lifecycle of the building. 9 of the houses do have solar photovoltaics which offsets the operational energy where the average household may not.

From the results we can also compare the effect of technologies such as Solar Panels and rainwater tanks with expected values and make assumptions as to why they may not be performing as well as expected or alternatively are performing better than expected.

This section goes through understanding the materials and appliances leading to the greatest embodied and operational energy for each dwelling. It also discusses the effect solar PV has on offsetting the carbon used by the home. The measured operational data for solar production is able to be compared against the eTool predicted value to explore the performance of the installed systems. A full breakdown of where the lifecycle impacts of each house occur can be found in appendix E.

It is important to incorporate the NatHERS Star rating to assist eTool in calculating the expected heating and cooling requirements of each house in addition to the other aspects of the operational energy.

4.2 Results

Note: it is important to consider the life expectancy assumed for each of the houses is 40 years. House G is the exception where 80 years was assumed given the housing type being a unit in a structure consisting of four homeowners. The LCA software assumed that having four separate owners makes it more difficult to redevelop given everyone would have to agree for it to occur.

4.2.1 Embodied Energy

The embodied energy of each dwelling varies due to the type and amount of materials used within the building. From Figure 5 it is clear that each dwelling has a different embodied energy. Varying from house H being above 4000 kg CO_2-eq/dwelling/year to house P having an embodied energy less than 2000 kg CO_2-eq/dwelling/year. The other housing including the benchmark houses range between these values. Further investigation into the eTool reports can show what the materials are for each house that contributes most to their embodied energy. The 10 houses have their embodied energy per year calculated based on a 40 year lifespan based on the location and being an individual dwelling. The exception to this is house G which has been determined based on the lifespan of 80 years due to the house being part of a complex with multiple owners and conjoining walls with other units.

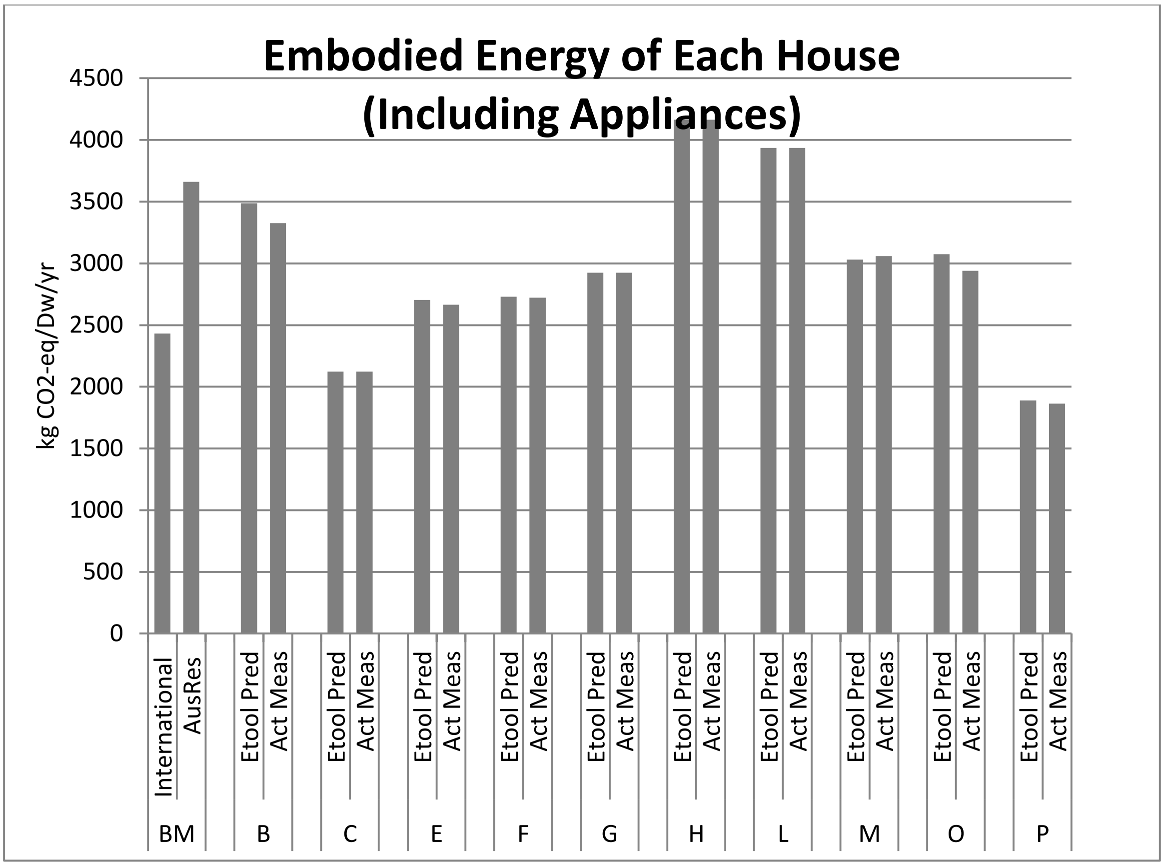


Figure 5: Embodied energy for each house (produced by Luke Murphy)
Note: eTool pred is measured as if the average person is living in the house, Act Meas is representing the embodied energy of the house with the appliances the occupants use

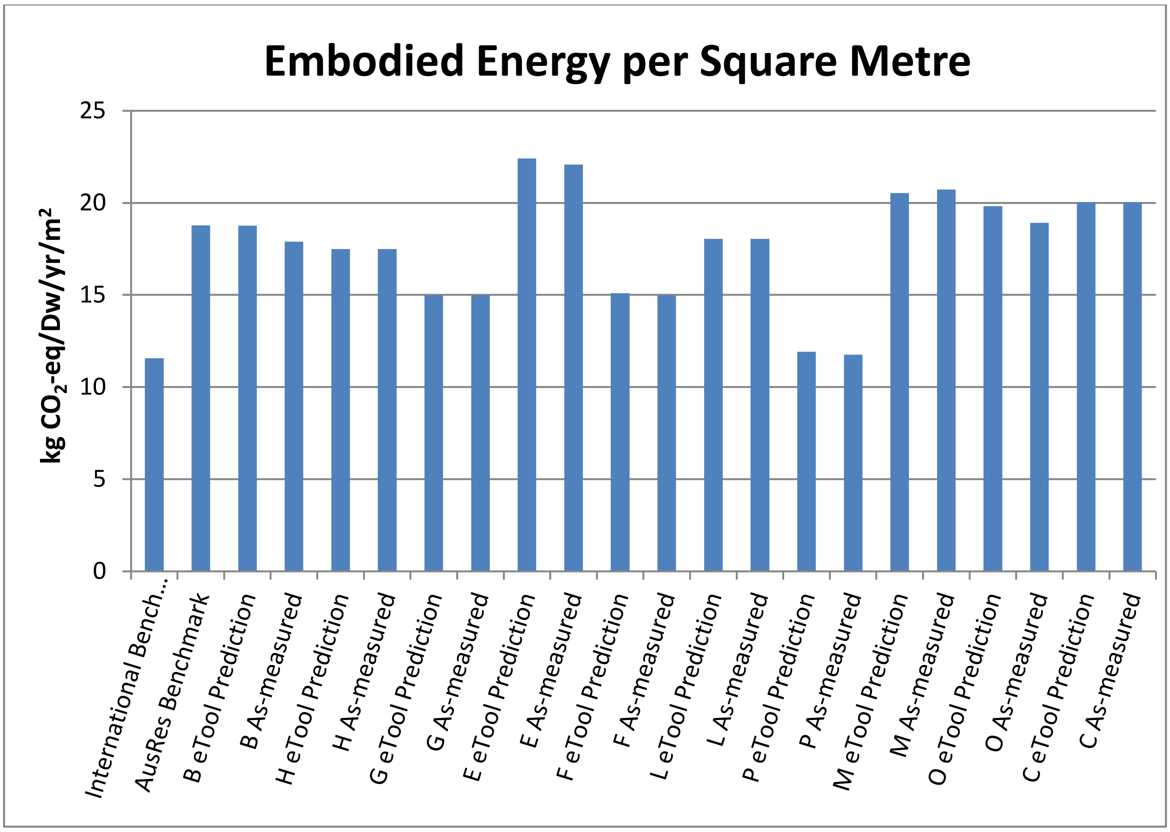


Figure 6: Embodied energy per year of each house per square meter (produced by Luke Murphy)

Figure 6 shows the breakdown of the embodied energy for each house per square meter of floor space. House E comes out as the highest embodied energy as this is a very old house consisting of thick limestone and brick walls in addition with the concrete pavers surrounding the house contributing to the high embodied energy per square meter. House P has a relatively low embodied energy as the retrofitted house is cladded lightweight construction with raised timber flooring. The new extension however does have a concrete floor to increase the thermal mass in the solar passive living room.

Figure 7 to 11 is a breakdown of the materials for the two houses with the overall highest embodied energy and two houses with the lowest embodied energy. The components can be seen in the graph with 'other' representing other materials included in the house that are not among the highest contributors where the top 30 for each house can be seen in appendix E.

The two highest being house H and L show that the brick construction and concrete pad are the two highest carbon dioxide contributors within the model. Houses C and P in figures 9 and 10 respectively are classified as lightweight construction with raised timber floors and fibre cement cladding. These two figures show that the highest single impact materials include the steel, refrigerants and the solar photovoltaic systems

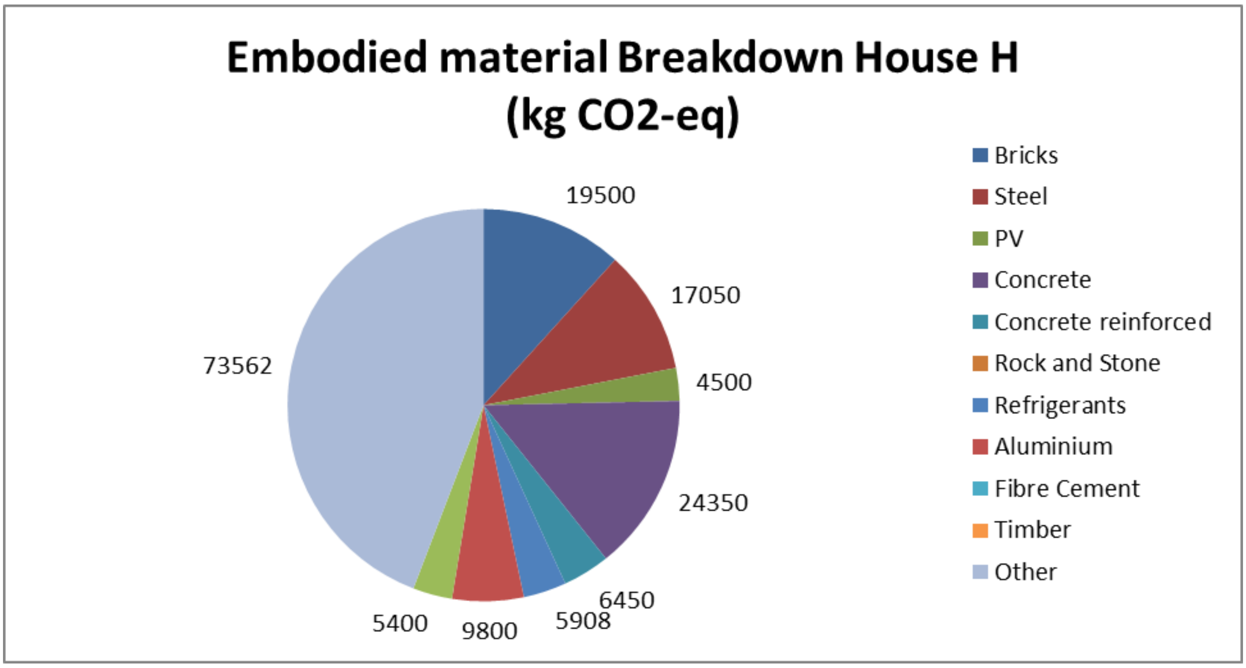


Figure 7 House H embodied energy breakdown of the highest contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the embodied breakdown

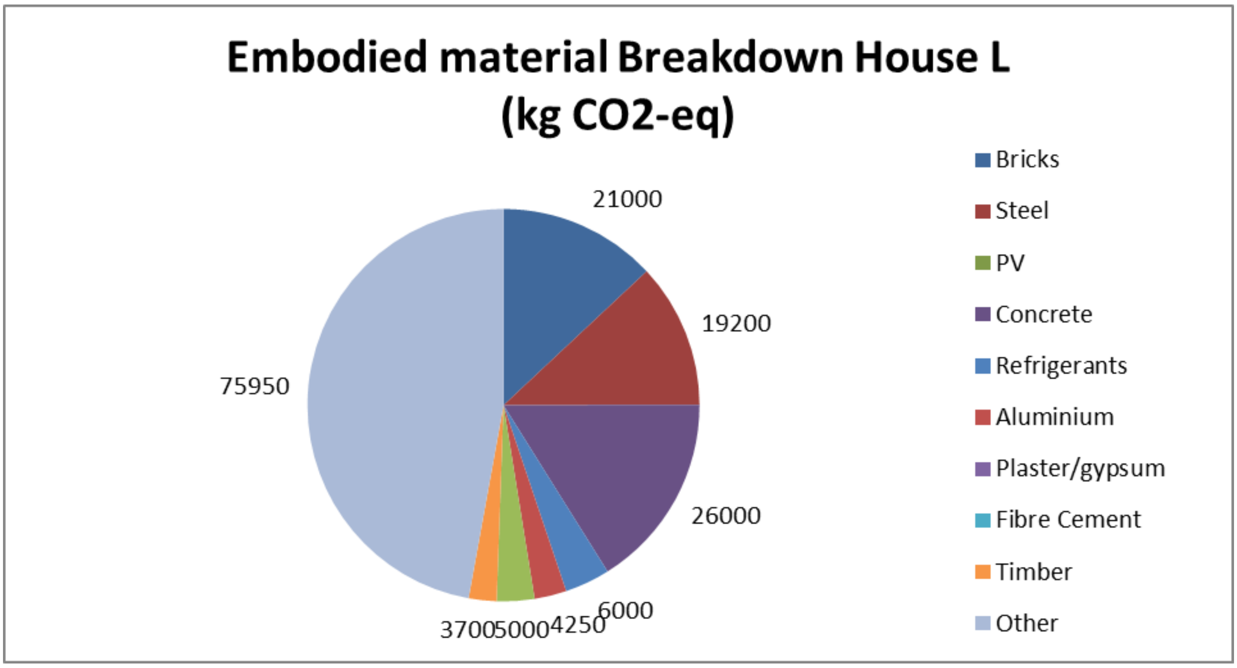


Figure 8 House L embodied energy breakdown of the highest contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the embodied breakdown

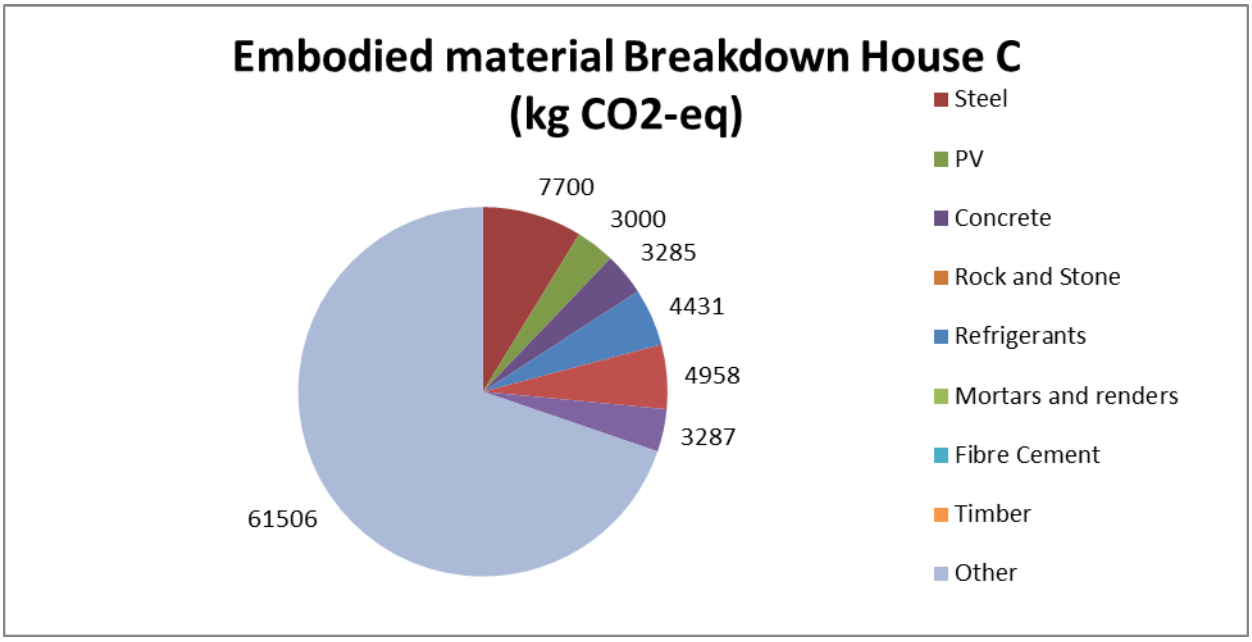


Figure 9 House C embodied energy breakdown of the highest contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the embodied breakdown

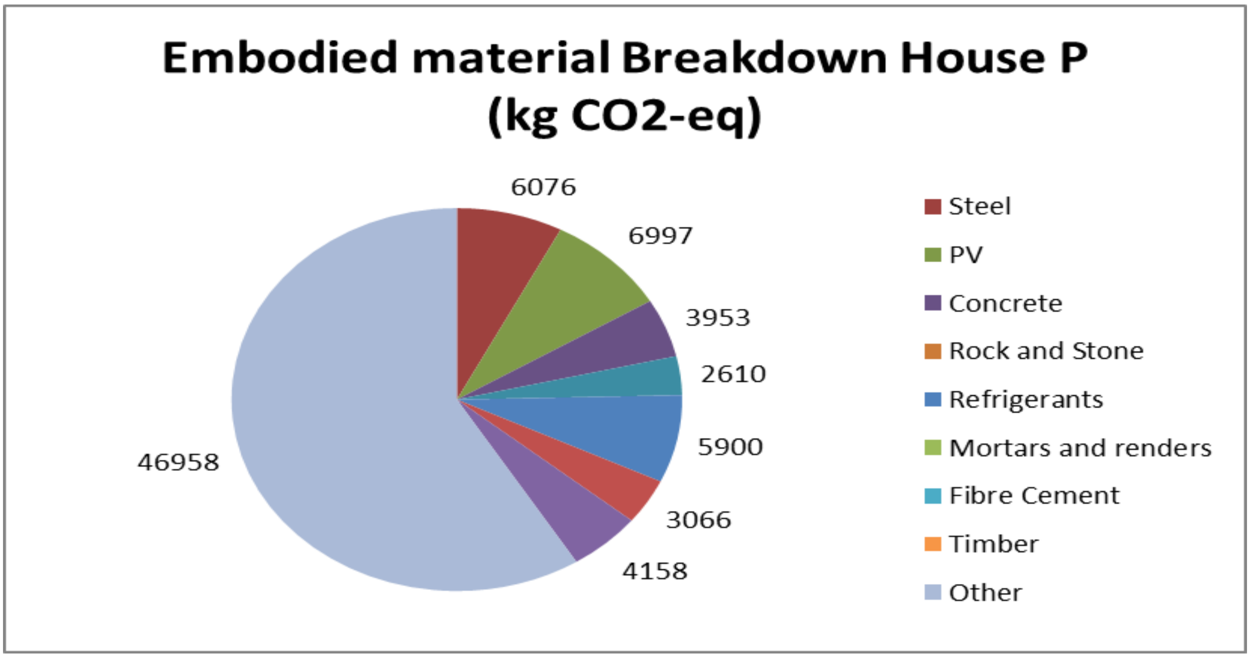


Figure 10 House P embodied energy breakdown of the highest contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the embodied breakdown

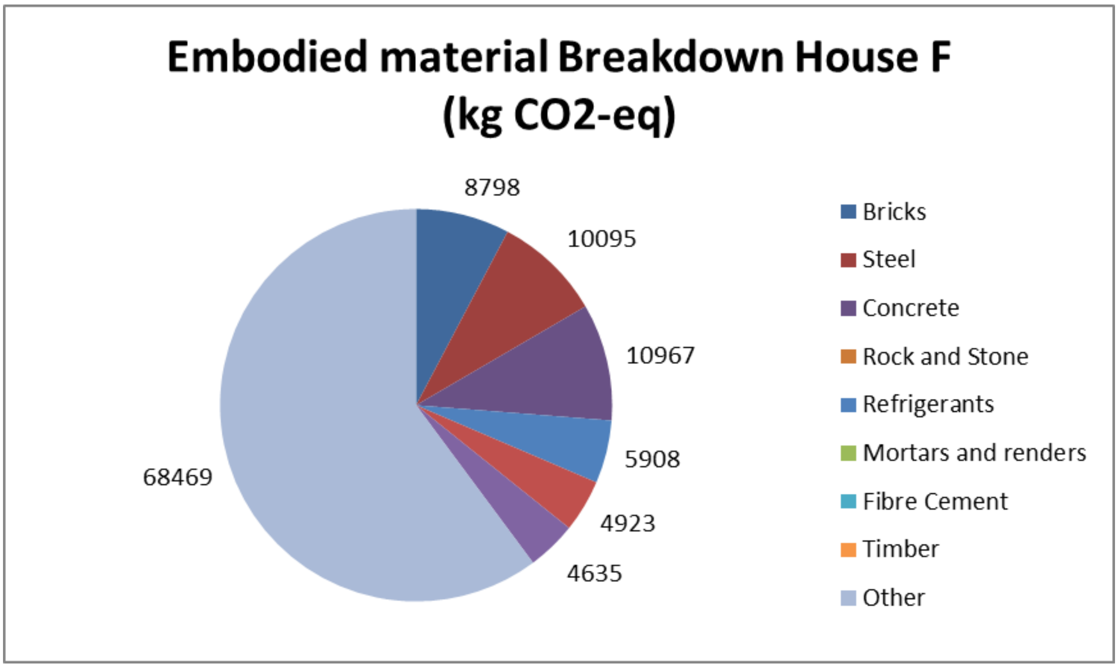


Figure 11 House F embodied energy breakdown of the highest contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the embodied breakdown

These comparisons are House F is a retrofitted house with the old section being traditional brick construction and the new section being lightweight bulk insulation frame with cladding. Figure 11 shows the highest impact being the concrete pad, followed by the roof and then the bricks from the old section of the house. This along with Figure 7 and 8 shows that double brick construction contributes to a high embodied energy within a house as does traditional concrete floors. The eTool software allows changes to be simulated such as floors using waste products such as fly ash instead of sand cement or different wall construction types such as using brick veneer or timber stud with bulk insulation to investigate the embodied energy reduction impact which can be useful during the design of a new house.

4.2.2 Operational Energy

The two ways operational energy is interpreted in this study is the global warming impact of operating the house and the unit measurements of kWh for energy and kL for water which is how the house is charged for the electricity and gas use and how occupant's best understand consumption of energy. The global warming impact is measured in kg CO_2-eq and represents the carbon emitted in the atmosphere.

Global Warming Impact

Figure 12 shows half of the houses have a measured lower operational energy than the predicted model with the other half having a worse operational energy than expected.

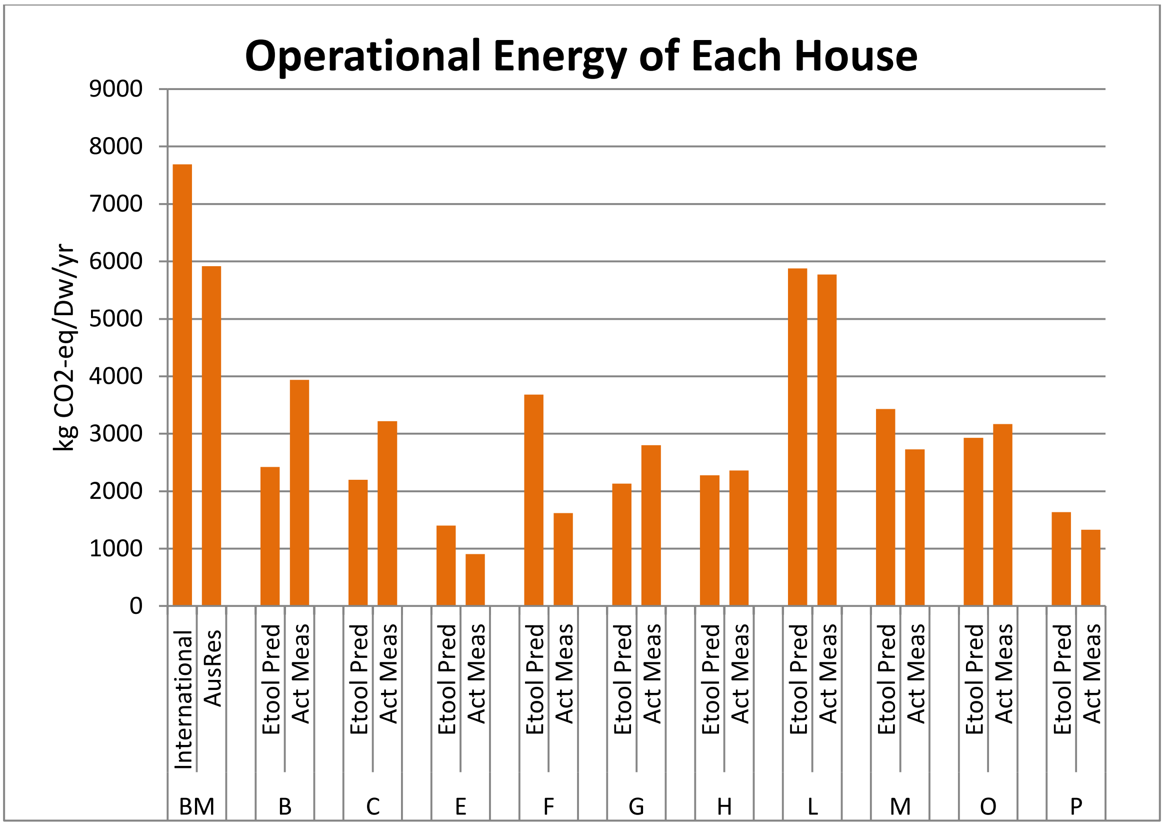


Figure 12: Total Operational Energy of Each house (produced by Luke Murphy)

The two benchmarks allow a comparison for how the houses operational energy compares to the eTool international average as well as the Australian average. A major factor in the benchmarks and house L having a much higher operational energy is that they do not have a photovoltaic system to offset the energy being used. This graph represents the carbon footprint of the grid electricity, gas and water usage and water disposal.

Similar to the embodied energy another graph was produced for the operational energy per square metre to determine a rating in correspondence with the NatHERS star rating. Figure 13 and 14 show the operational energy without and with photovoltaic production respectively. This shows the impact solar energy has on the overall operational energy as with it not taken into consideration house M and P have the highest operational energy per square meter. However with the solar offset included, they are much lower with the benchmarks and house L having the highest operational energy per square meter.

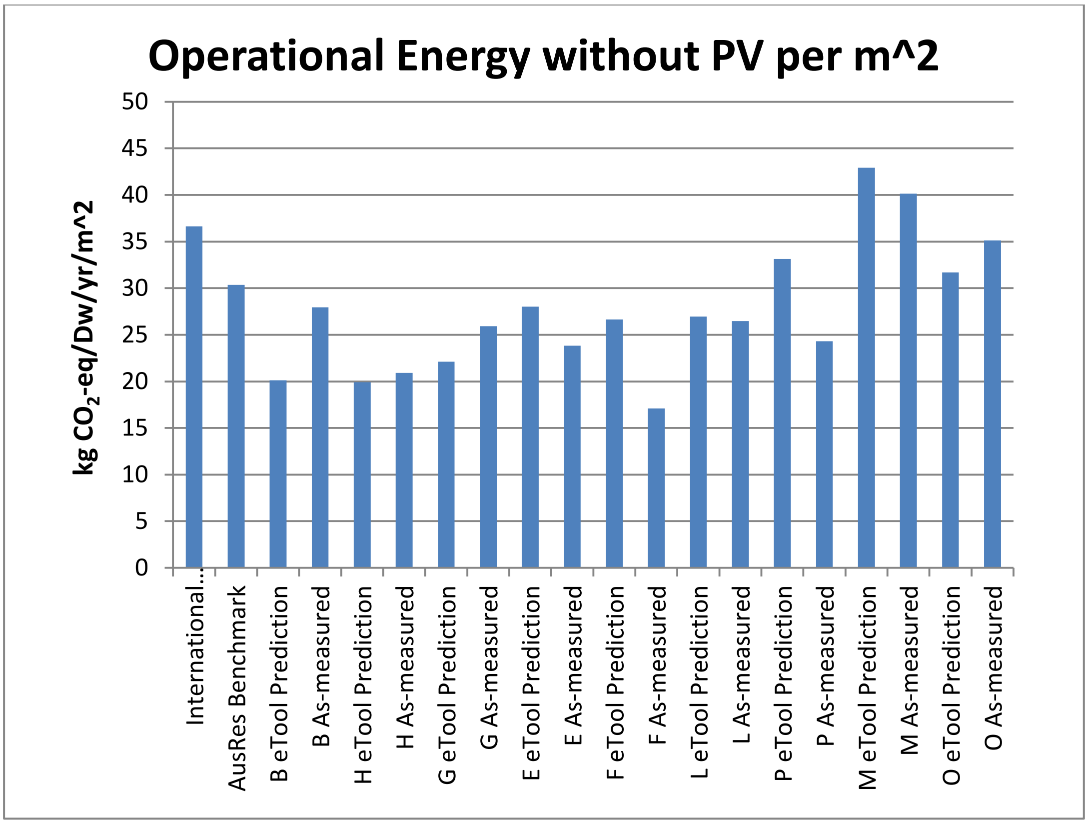


Figure 13: Operational Energy per square meter for each house with photovoltaic not taken into consideration (produced by Luke Murphy)

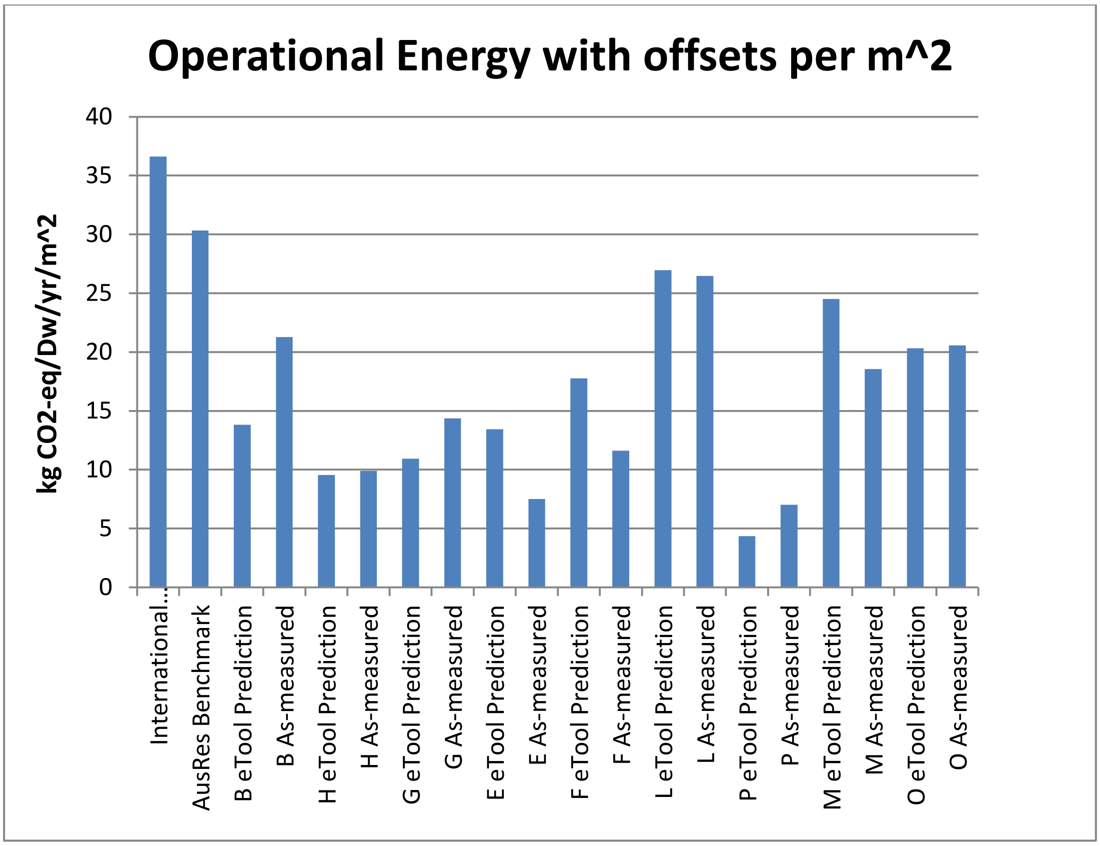


Figure 14: Operational Energy per square meter for each house with photovoltaic taken into consideration (produced by Luke Murphy)

eTool can show the top impacts report for the highest operational energy appliances. From Figures 15 to 24 show the factors that most influence the operational impact for each house. From this report, the areas with the highest impact can be targeted so that strategies to reduce the impact can be taken into consideration. An example of an efficiency improvement which can reduce the operational energy is house M, where by changing the halogen downlights to LEDs shows a change from 8831MJ/year to 1089MJ/year which is a reduction of 1700kg CO_2-eq/year. From the models the refrigeration operational energy is quite high which includes the operational running costs and re-gassing every ten years. Purchasing refrigerators with high efficiency and good build quality can increase the lifespan and reduce the energy use of the refrigerators to reduce the operational carbon footprint of the appliance. The 'other' category is a breakdown of the smaller single operational energy uses which are most likely to have less of an impact to the global warming potential.

In addition the eTool model predicts the hot water demand for a solar hot water system with gas booster is 1000 MJ, where the electric boosted solar hot water prediction is that it requires 1644MJ of electricity to run, the instant gas requires 7545MJ per annum to run however gas has a much lower carbon footprint than electricity. This gives a good prediction of possible savings by installing a solar hot water system. However it is important that they are installed in the correct place where it will receive minimal shading, otherwise it is possible that it will perform worse expected and can end up being less efficient than a single instant gas system.

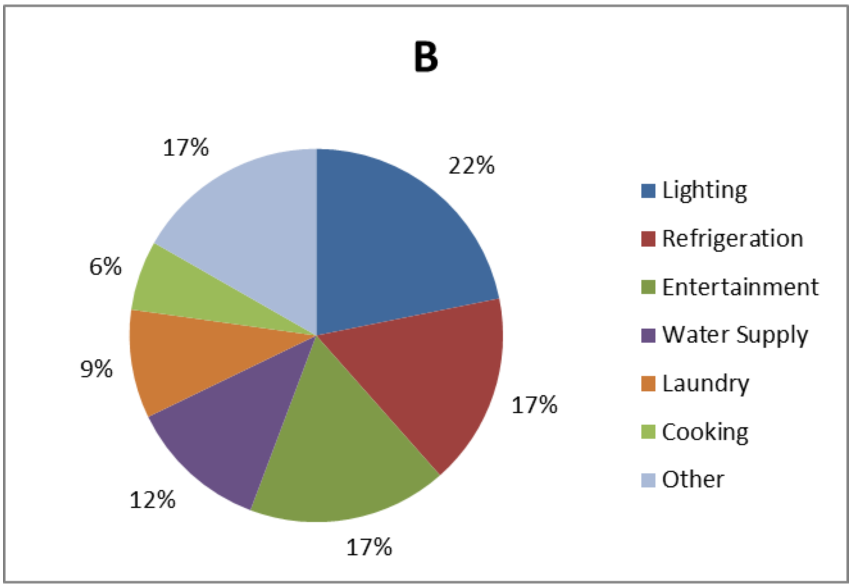


Figure 15 House B highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

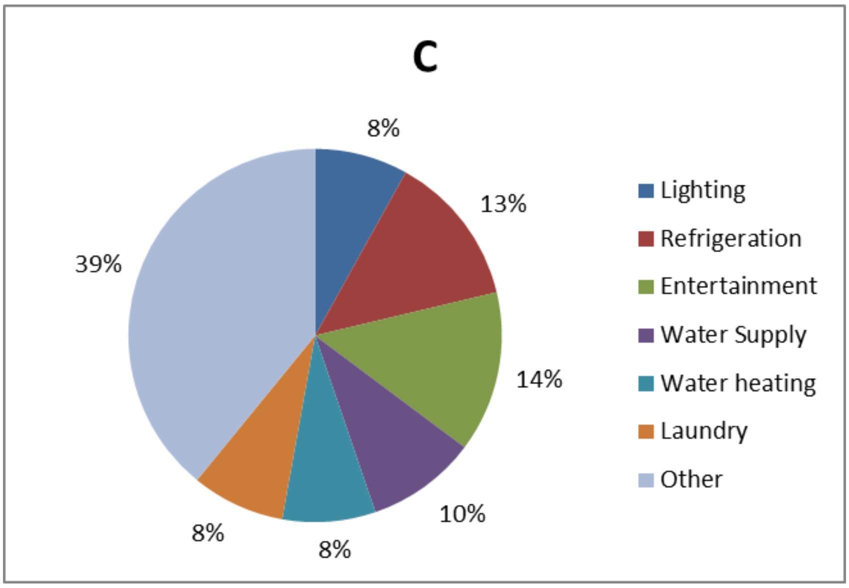


Figure 16 House C highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

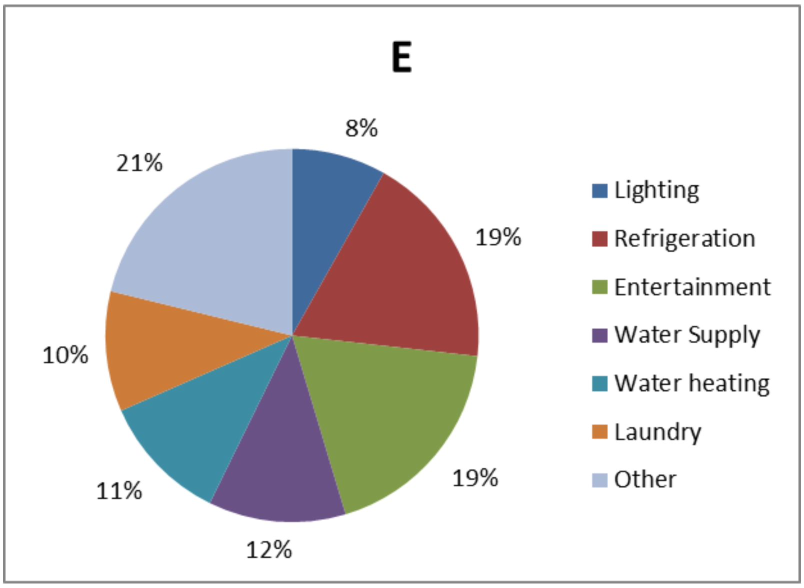


Figure 17 House E highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

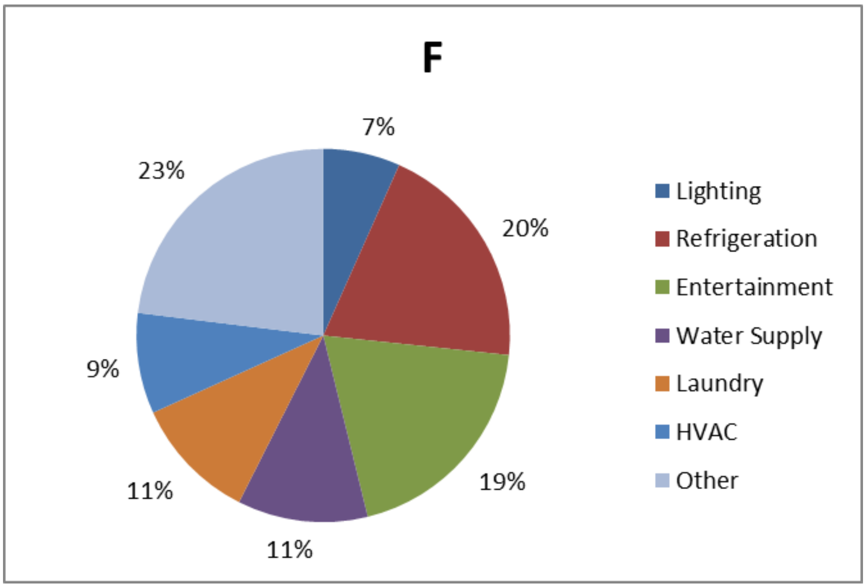


Figure 18 House F highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

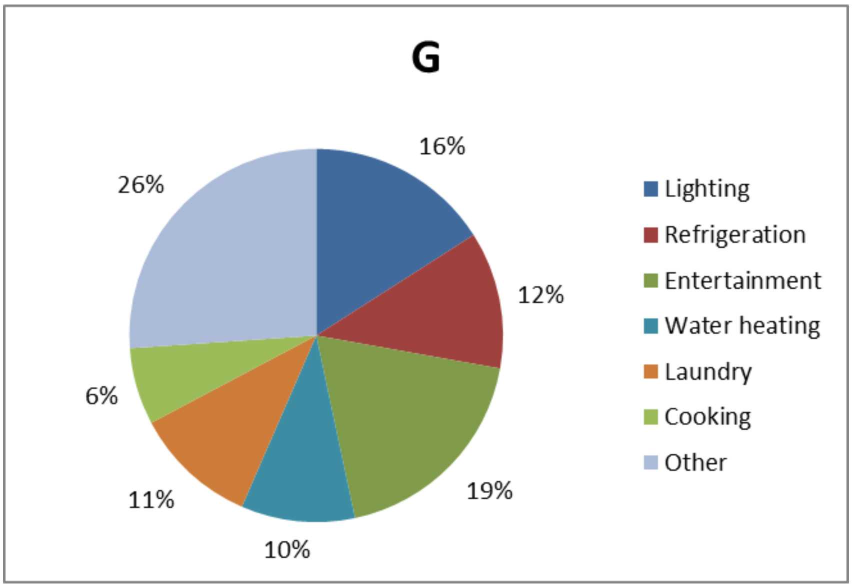


Figure 19 House G highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

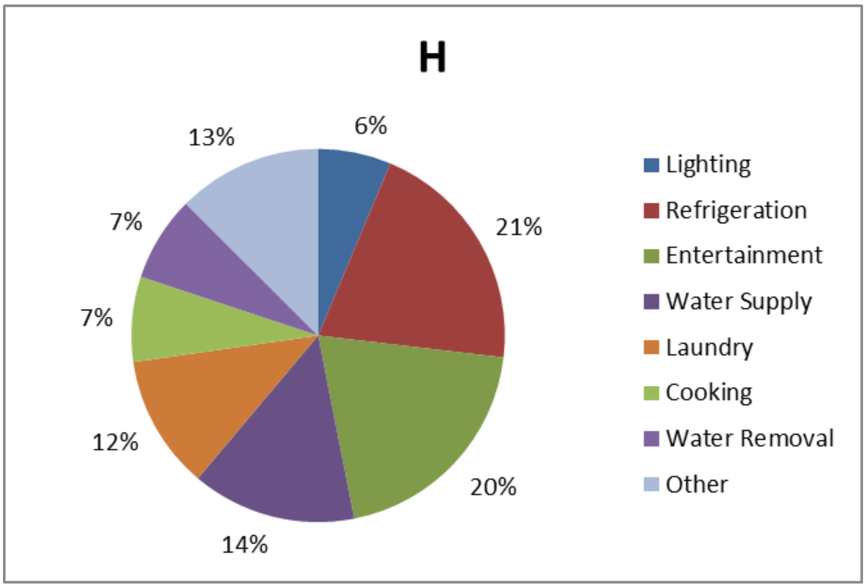


Figure 20 House H highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

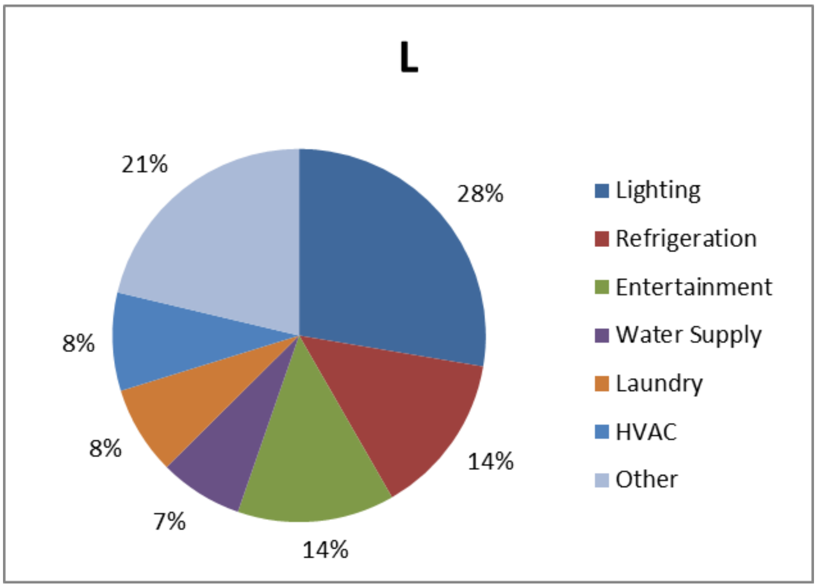


Figure 21 House L highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

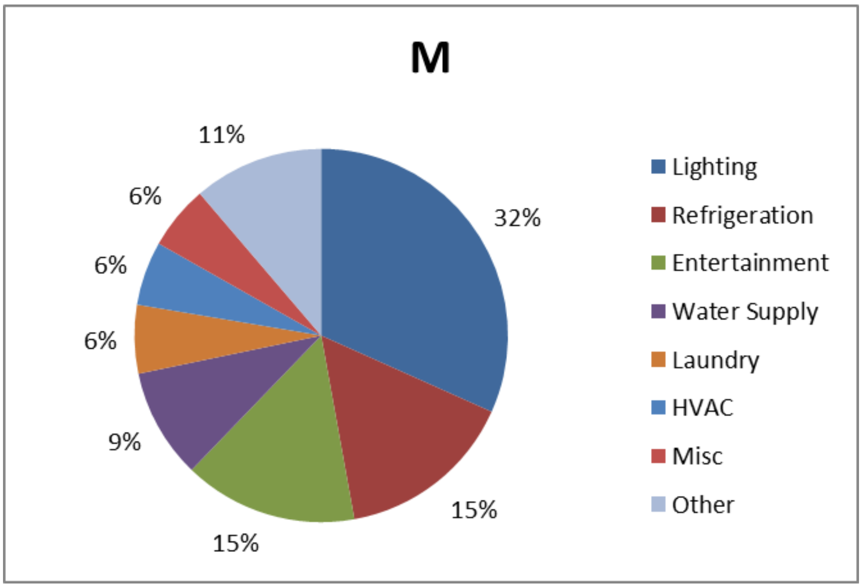


Figure 22 House M highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

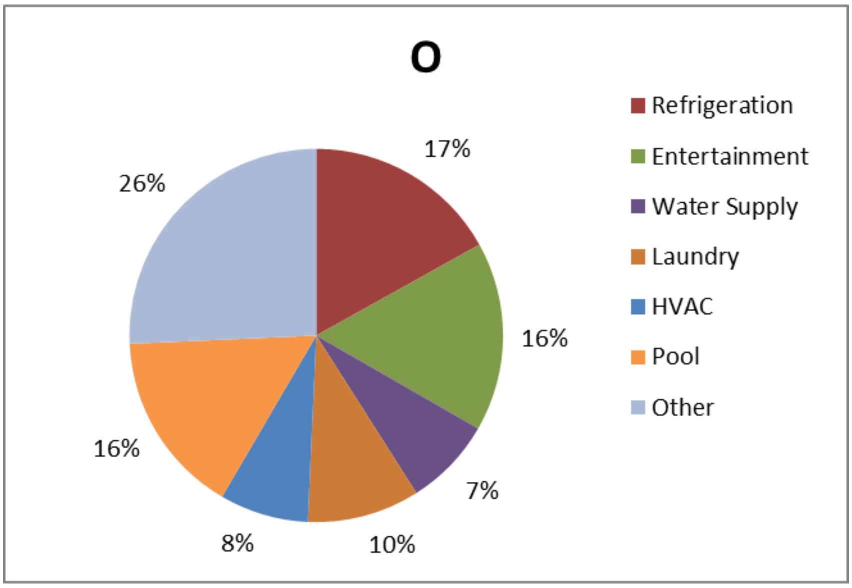


Figure 23 House O highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

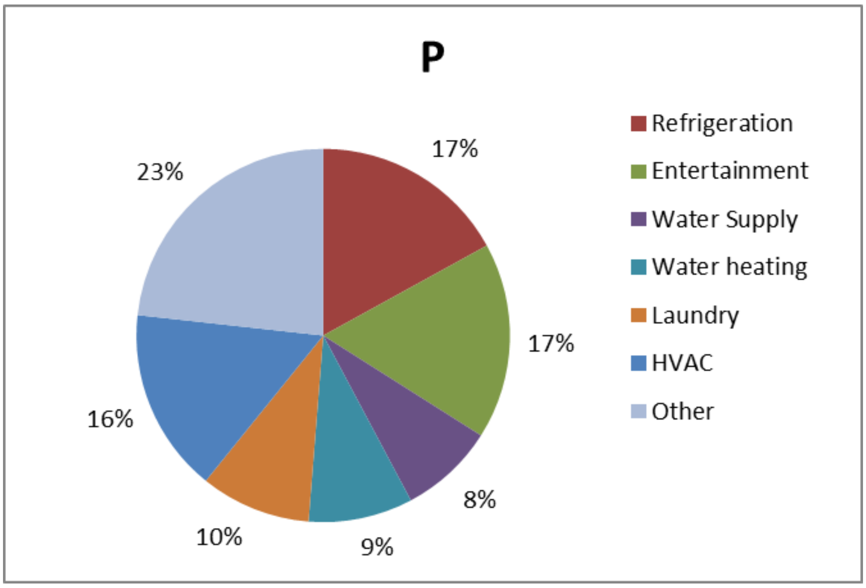


Figure 24 House P highest operational energy contributors (produced by Luke Murphy)
Note: Other represents the sum of the lower individual contributors to the operational breakdown

kWh

Along with the global warming potential for the operational energy, the eTool report specifies the operational energy in kWh for electricity, gas and solar energy produced. The importance of this is that owners and developers are able to compare products in a monetary term which includes the savings they will make by reducing the operational energy and some pay back periods can be calculated to help make certain decisions or technologies.

Figure 25 shows the total grid electricity used in the eTool predicted and the measured operational data for each dwelling. House H has an inefficient electric boosted solar hot water system due to it being shaded in summer as well as electric bar heaters which could contribute to the higher operational electricity being measured than expected. House F has a much lower operational energy than predicted; this could be due to a wood fire being used in winter for heating as well as the highly insulated extension and efficient energy practises ensuring the electricity use is kept low.

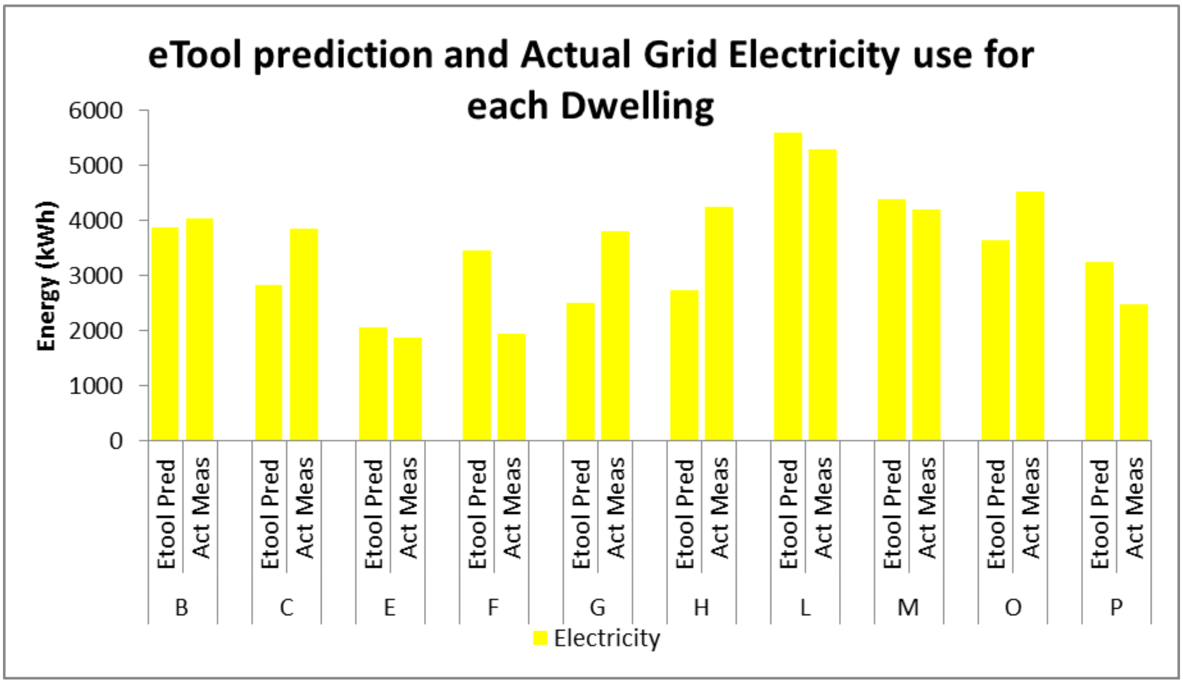


Figure 25: Electricity use comparison between the eTool prediction and measured operational measurement (produced by Luke Murphy)

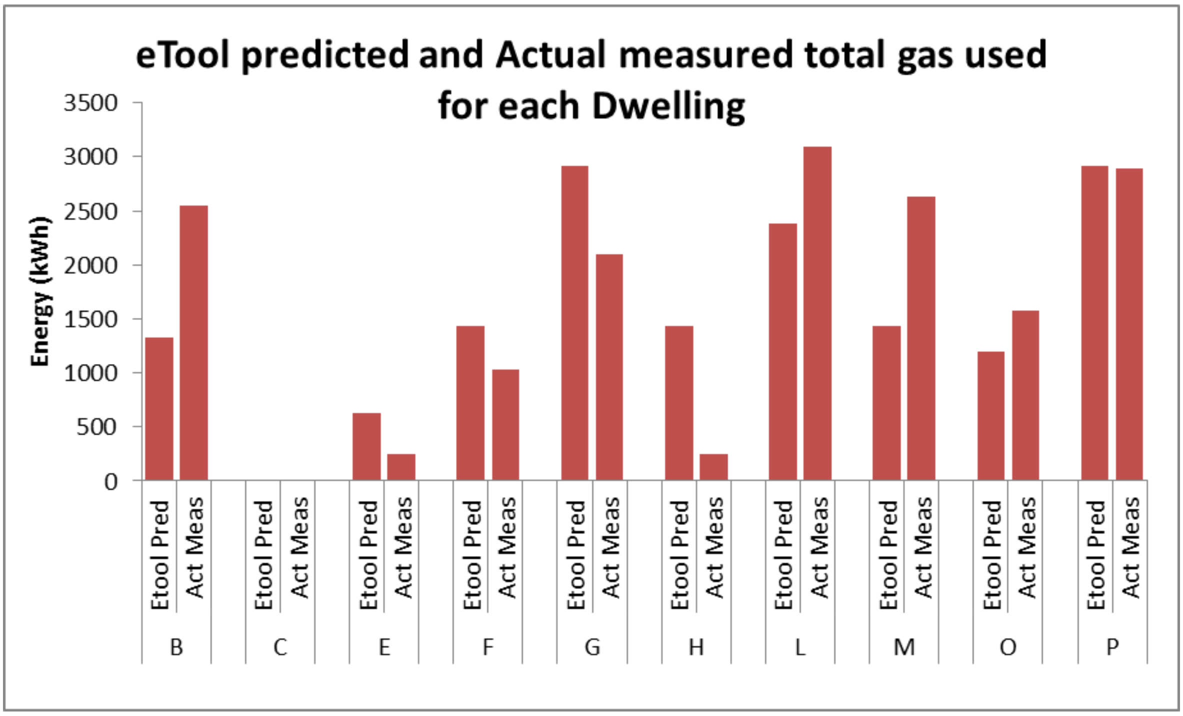


Figure 26: Gas use comparison between the eTool prediction and measured operational measurement (produced by Luke Murphy)

Figure 26 shows the total gas used in the eTool predicted and the measured operational data for each dwelling. There is no gas used for house C as the owners identified that gas is not a renewable resource where electricity can be produced by solar and wind technologies. House E has relatively low gas use due to only the gas cook top using gas, which uses slightly less energy than predicted. House H uses gas for cooking and a solar hot water heater booster, the measured value is much lower which is due to a highly efficient Apricus evacuated tube solar hot water system. In addition house M has the same gas requirements as house H, but in reality the house uses much more gas than predicted. This could be due to the inefficient hot water system being shaded for long periods and not working efficiently.

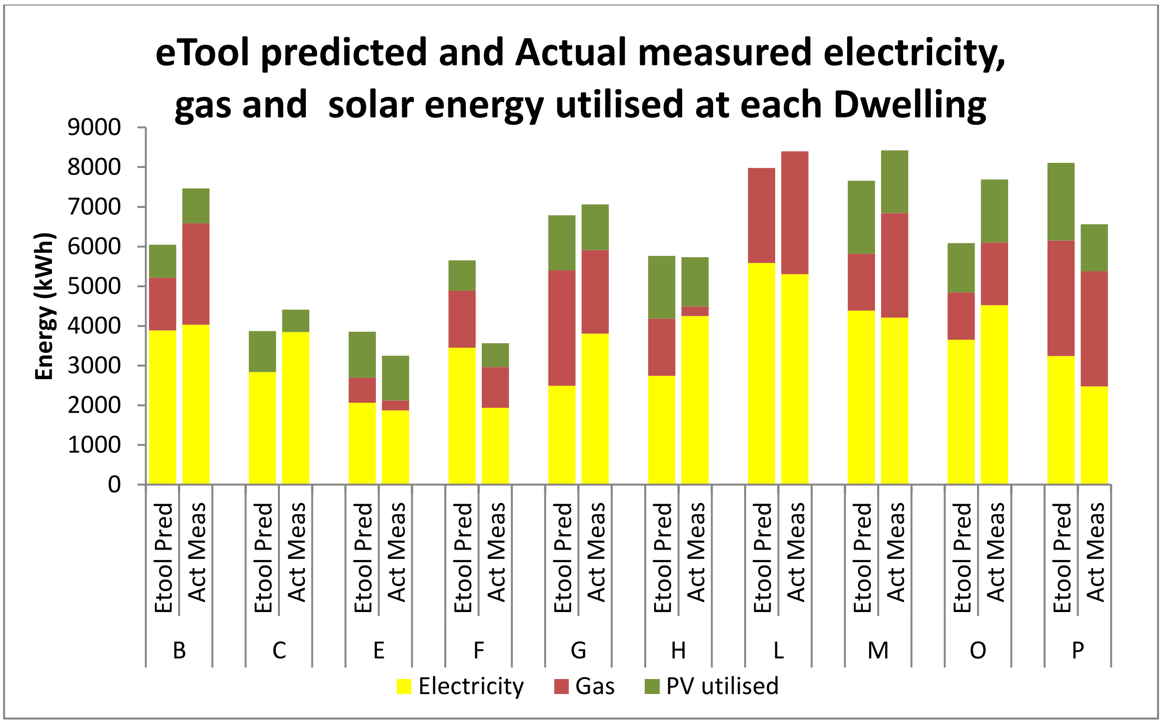


Figure 27: Total electricity demand of all the dwellings insluding the solar energy used in the house (produced by Luke Murphy)

Figure 27 shows the amount of energy that would be used if there was no solar PV to offset the energy use. This graph is particularly useful to compare house L with the other houses showing that houses M, O and P actually have a similar energy demand, the only difference is house L hasn't got any green energy offsetting the energy bill other than the solar hot water system, which isn't measured independently.

As discussed, the eTool software can be used to firstly roughly estimate the energy use, the operational energy from one year can be compared with the prediction to see if there are certain behaviours or technology inefficiencies leading to an unexpected increase in performance.

Carbon Offsets

The solar energy production was added to the operational energy to get an understanding of the performance in comparison with each other before the offsets take place. Figure 28 shows that even if none of the houses had solar panels, house L would still have the greatest total global warming potential apart from the international benchmarks. This house is rated at six stars yet it is has a higher global warming potential than the old retrofitted houses P, C and F

Figure 28 is an intuitive graph which represents the data that is required for an Australian residential dwelling to reach the European Union's standard of zero energy or carbon neutral. Ideally a LCA would be initially used to identify changes to the materials used within the dwelling to reduce the embodied energy while maintaining or increasing the thermal performance. Options can then be identified to reduce the total operational energy by choosing energy efficient appliances, efficient water heaters and using ceiling fans as the preferred cooling option. Once the embodied and operational energy is reduced, renewable carbon offsets such as solar photovoltaic systems can be sized to offset the remaining expected operational and embodied energy to become net zero or possibly even produce surplus energy to benefit other households.

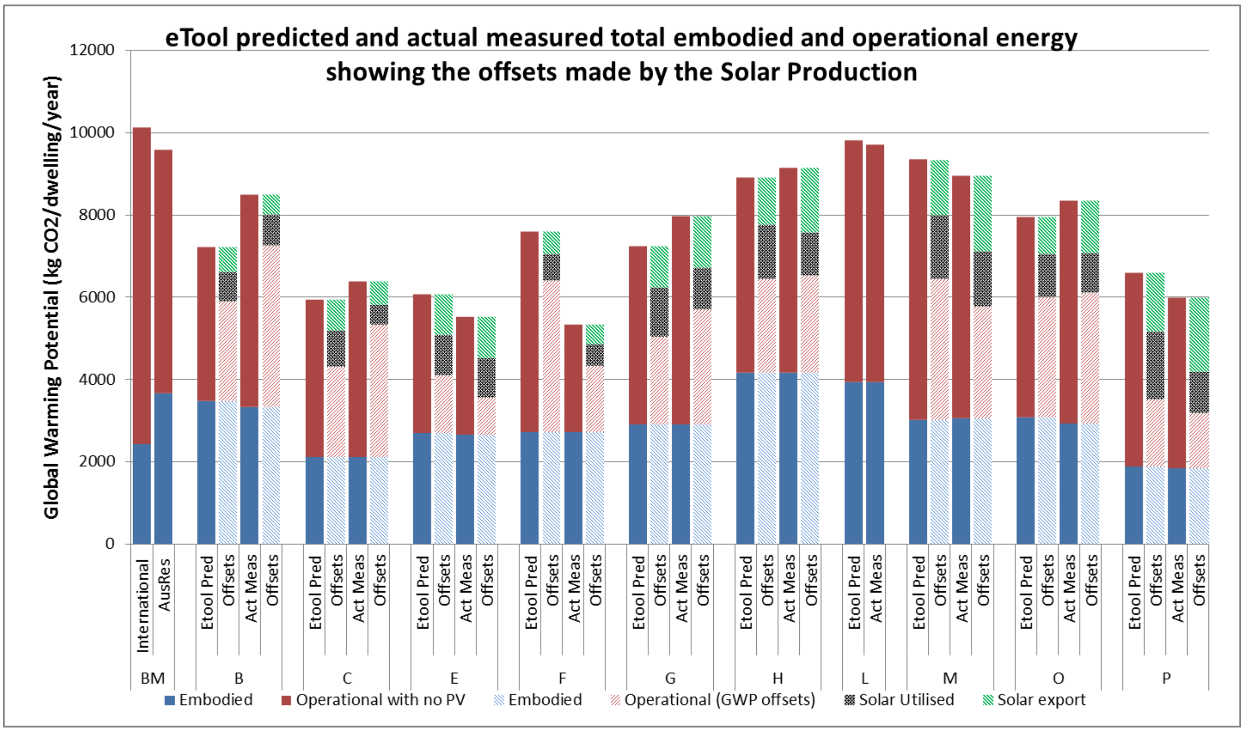


Figure 28: The embodied and operational global warming impact of each house showing the offsets from renewable energy (produced by Luke Murphy)

Photovoltaic Predicted Vs Actual Measured

The results in figure 29 show that there is a slight variation between the measured photovoltaic production and the eTool prediction. Six of the nine houses show a better performance than the eTool template expects, this could be due to a number of factors which could include correct orientation, a higher efficiency system than expected or a larger sized system. House C and F's lower than expected performance can be contributed from large trees shading the system which confirms the importance of positioning the photovoltaic panels in the correct place so they receive the maximum possible sunlight. Another important note is that house C washed the collector plates during the second year of the study so it would be interesting to see if the production increased at all after this. House P has a large system, however this system is positioned on a south facing roof and it can be seen in the graph the effect on the production this has in comparison with the predicted measurement. An unexpected value is house H system performing better than predicted given the knowledge that the system was off for a period of time during the year. This shows the performance of the system is good, but would be even better if it wasn't prone to tripping in wet weather events.

The photovoltaic comparisons provide an insight into the modelled and actual production of a range of photovoltaic systems. The graph shows that it is very useful to 'ground truth' how the system is performing so any deficiencies can be identified and possibly improved to further increase the carbon offsets of the system.

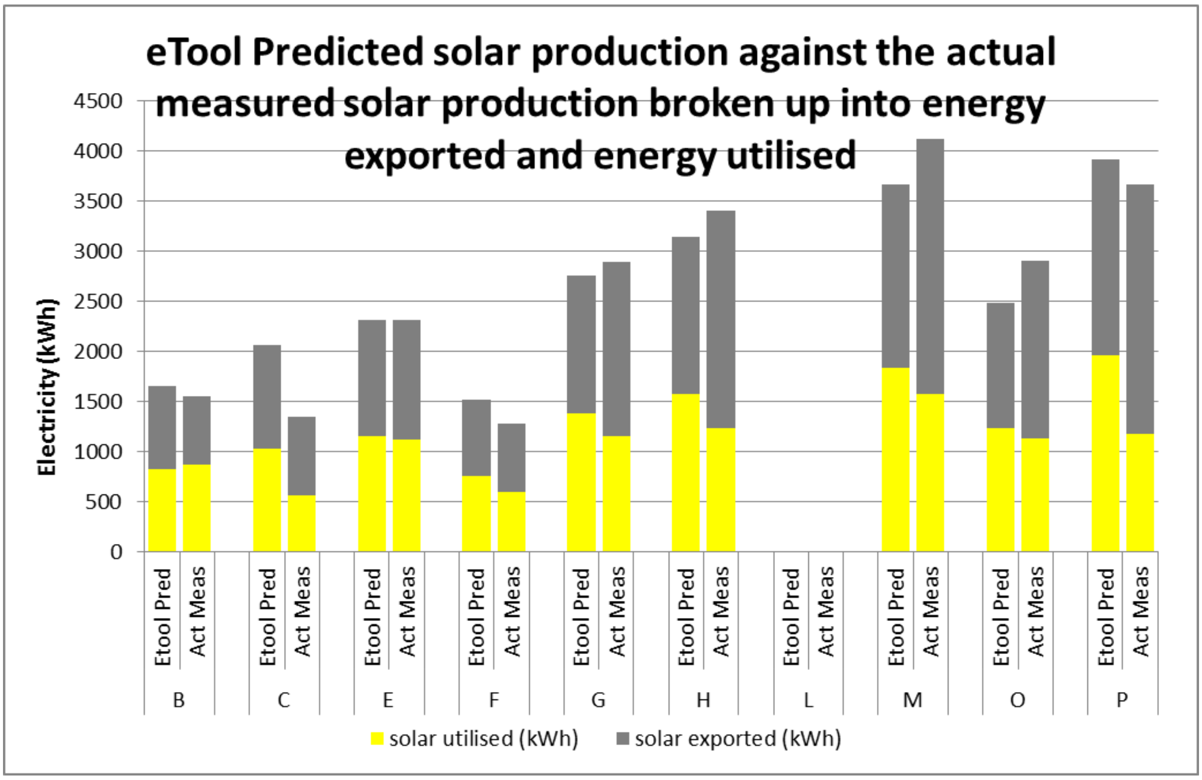


Figure 29: Photovoltaic comparison with solar production broke down into solar utilised and exported compared to expected production (produced by Luke Murphy)

Photovoltaic Utilised Vs Exported

The eTool template for solar energy assumes that there is an equal distribution between solar energy utilised and exported for each house when in reality this depends on the occupants of the homes behaviours and activities. Figure 30 shows that house B, C, E and F have a relatively equal distribution between solar energy utilised and exported. Houses G, H, M, O and P have a much higher exported component which can indicate that they have larger systems or can utilise the solar production by running appliances during the day.

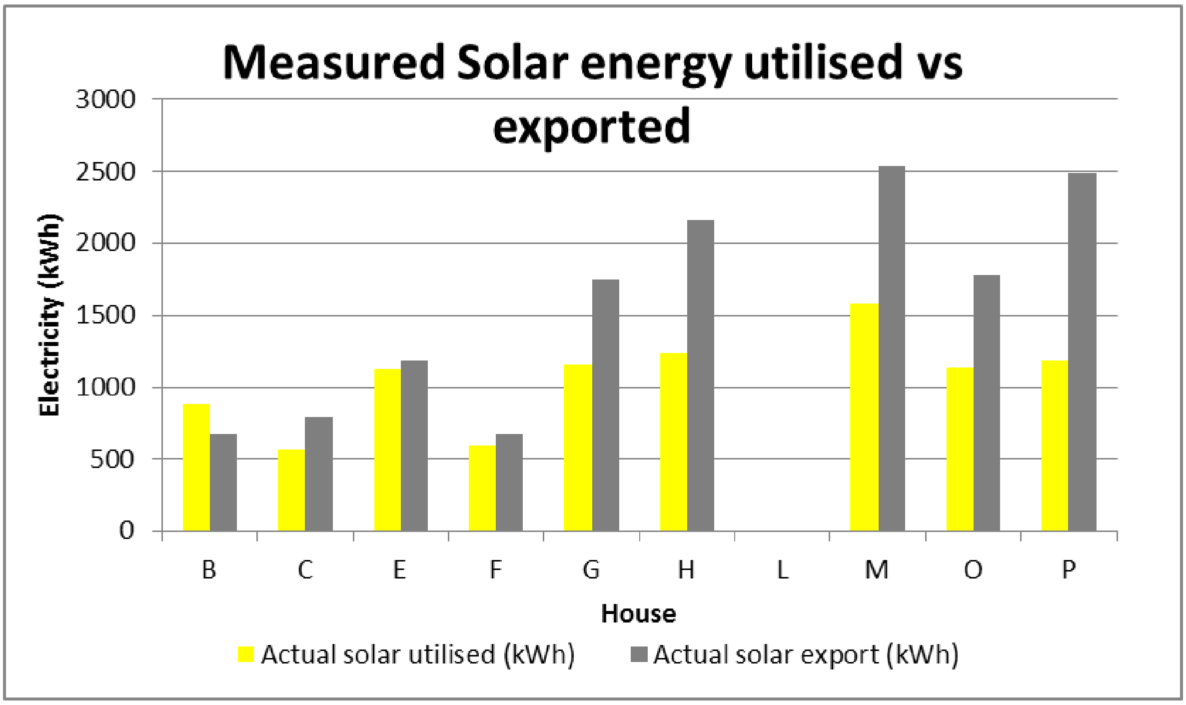


Figure 30: Actual breakdown of measured solar energy utilised and exported for each house (produced by Luke Murphy)

5.0 Thermal Performance Efficiency and Behavioural Change

5.1 Introduction

The advertisement for houses to participate in the study appealed to environmentally conscious occupants who had previously retrofitted their home to be more efficient or had built new homes that were compliant with the most recent NatHERS 6 star rating. Although these occupants are already environmentally conscious it was evident that the results showed there were some areas of efficiency improvement that had not yet been identified from living in the houses. The first year of data was a great insight into where many of the efficiency improvements could be made without visiting or speaking to the occupants living in the homes.

To confirm these assumptions an interview and audit was conducted with the homeowners for nine of the ten households. The interviews were designed to find out how each house was operated and to consult with the homeowners to improve appliances or behaviours that were degrading to the homes performance in addition the interviews helped to confirm any assumptions made from the graphs prepared prior to the audit. A major component of the audit was to look for building inefficiencies caused by poor design, poor installation or other factors which would improve the performance of the house and save on utility expenses while enhancing the comfort of each house.

The results determined there were some common efficiency improvements which could be applied to more than one house, including common energy usage behaviours and trends.

5.2 Results and Discussion

House B had a change of occupancy prior to the second year of monitoring which meant that the data gathered for the first year was not necessarily relevant to the new tenants as it would show the previous tenants' behaviours. No audits were completed as the results were not relevant to influence behavioural change for this house. A separate investigation once both years of results are finalised will provide a better comparison in behaviours influencing the performance of this house. As a result there will be no findings for house B presented in this section of the paper.

5.2.1 Inefficiencies from building design

Inability to heat purge in summer

Figure 31 shows inefficiency due to behaviour and house design. During the audits it was noted that some of the newly built houses had a front wooden door at the entry of the house without any security flyscreen material resulting in the occupants not feeling secure enough to leave their door open and allow air to pass through while the house remained locked. Buildings in

Perth, Western Australia are typically built with a high thermal mass which work extremely well to keep the house cool during summer and warm in winter. This practice is known as heat purging and works in summer by allowing the cool air at night to cool the internal walls to be stored throughout the next day. Not having a security screen on each window discourages people and makes them unwilling to leave these doors open to let a cool breeze into the house. An example of this can be seen in figure 31, when the front door is not opened there is very little movement of air through the house but with the doors and windows open the arrows show the likely air movement with the typical southerly breeze.

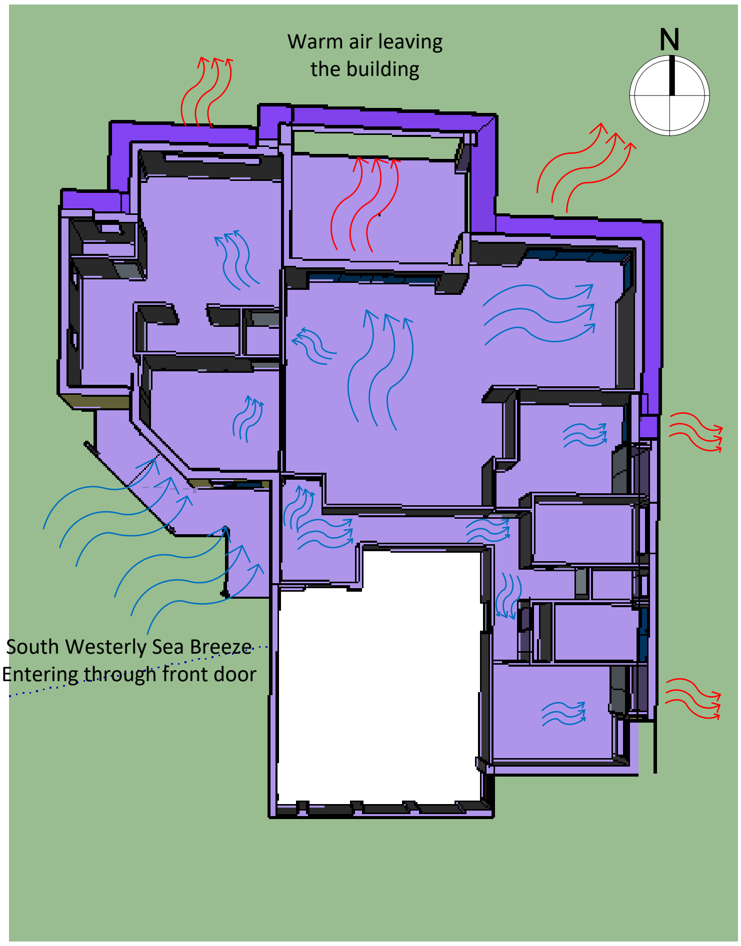
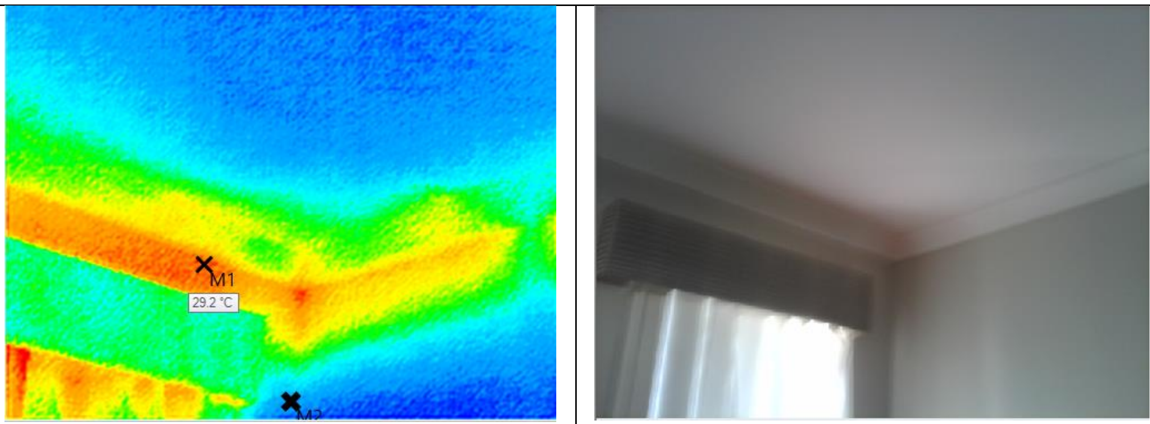


Figure 31 Movement of air through the front door of house O which isn't possible due to the impermeable front door (produced by Luke Murphy)

Heat gained and lost from missing insulation

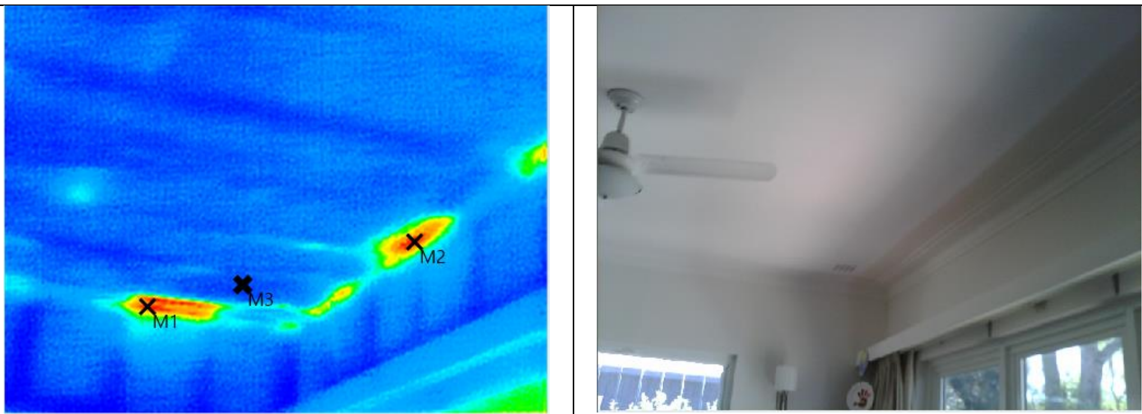
Figure 32 shows a thermal image of a double brick wall at house M which allows us to see how much the heat can increase in summer. Figure 32 shows what happens when there are gaps in insulation typically around the edges of a room. The thermal imaging camera shows the temperature M1 as 29.2 and the rest of the room M2 at 26. This image shows the importance of extending the insulation to the top of the ceiling so there are no gaps for heat to be gained in summer or lost in winter.



M1: 29.2°C, M2: 26°C

Figure 32: Thermal image of corner of the ceiling showing insulation missing (Source: Christine Eon 2015 audit report)

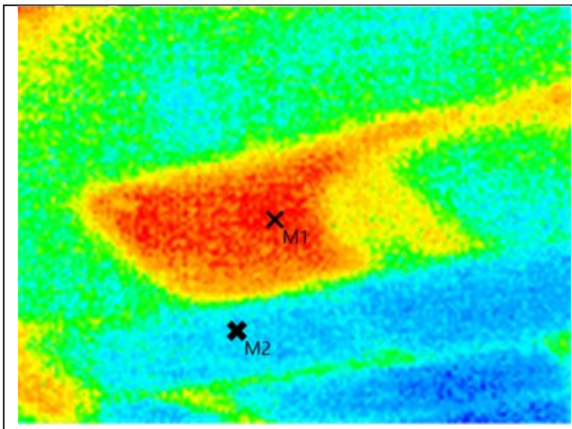
House C; is a retrofitted 1940's style home in Hilton. The homeowners have insulated the cladded timber stud walls and the roof to increase the thermal performance of the house. Figure 33 shows the roof and walls being insulated thoroughly, except where the roof insulation is supposed to connects to the wall insulation. It becomes very difficult to rectify this problem once the house is built so careful placement of insulation during the building phase can maximise the effect of the insulation.



M1: 36°C, M2: 35.2°C, M3: 27.3°C

Figure 33: Insulation missing around the edges of house C (Source: Christine Eon 2015 audit report)

House O; it was found that there is missing insulation around the downlights in the roof. This is common when the downlights are installed that the insulation is pulled clear and not put back. It can be seen in figure 34 that the section around the downlight is 3 degrees warmer than the rest of the roof meaning heat will be gained and lost through the missing insulation. It is important to identify which light types can allow insulation to cover them and which need to be left clear as this can reduce the thermal performance of a house if a gap in the insulation is required.



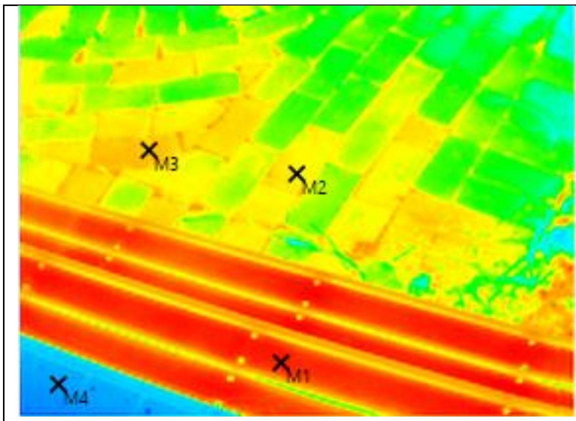
M1: 26°C, M2: 23.3°C

Figure 34: Missing insulation around downlight at house O (Source: Christine Eon 2015 audit report)

Heat gained and lost from windows

An important consideration when designing houses is shading external windows including the groundcover beneath the windows.

Figure 35 shows the importance of shading outside patio areas including windows. House C has bricks that are exposed to full sun and record a reading of 70°C in the middle of the day and the dark timber is at 80°C. The shaded timber is half the temperature at 40°C as shown in figure 35. This supports the consideration needed at design stage to reduce the heat radiation being emitted from the hot surfaces surrounding the house which can enter the house through a window.

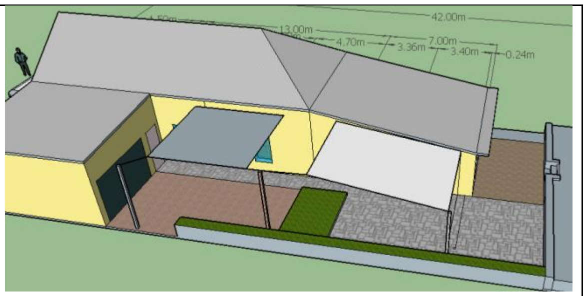
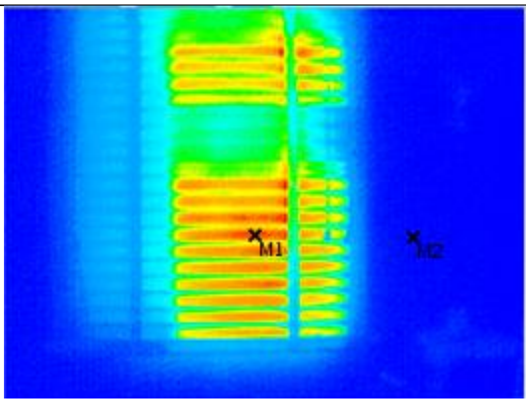
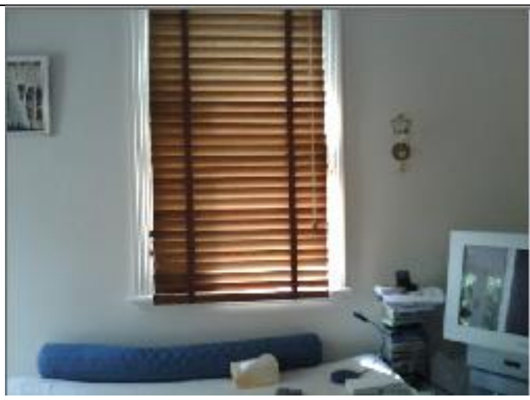
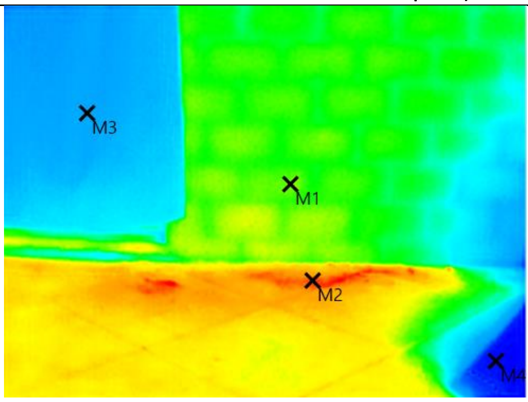


M1: 80°C, M2: 66.4°C, M3: 70.4°C, M4: 40.9°C

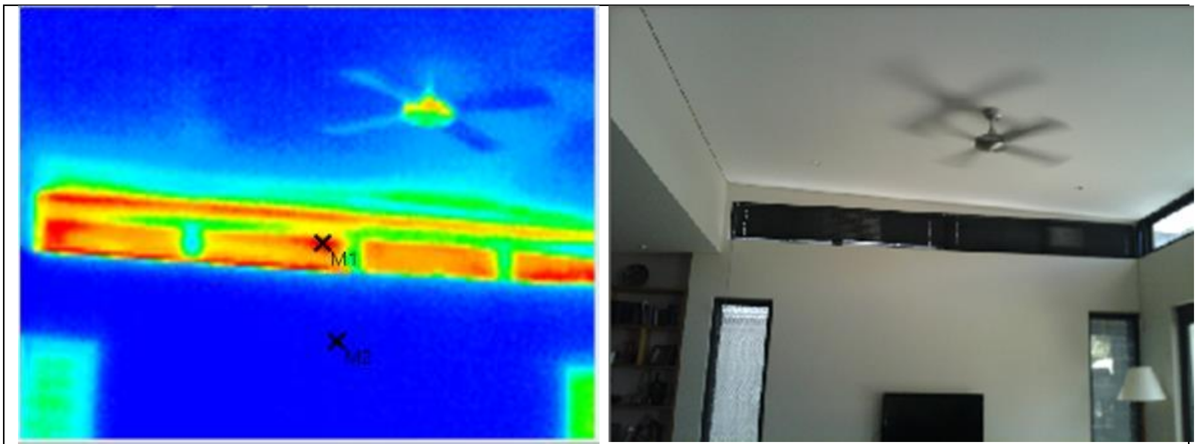
Figure 35: Temperature of a deck in shade compared to when it is in direct sunlight at house C (Source: Christine Eon 2015 audit report)

House E contains east facing windows which can be seen in figure A and B in table 7. The west side of the house is protected from solar gain as the boundary is against another house; however the east has windows are unshaded from the morning sun throughout the year. The occupants already demonstrate a good practice which includes shading the insides and outsides of windows with fabric to reduce the amount of heat entering the window in the morning. Even when this is done the internal temperature of the window is 13 degrees warmer than the nearby wall which can be seen in image C of Table 7. To further improve the efficiency it would be beneficial to shade the outside of these windows during summer to keep the surrounding concrete cooler. A semi-permanent shade-sail is the most cost effective way of achieving this due to the ground cover being concrete which heats up throughout the day, radiating heat through the night keeping the house warm. Part B of table 7 shows the proposed design to increase the thermal efficiency of the house to shade from the morning sun.

Table 7 East façade of house E

 A. Outdoor east windows	 B. Proposed shade solution
 C. M1: 38.2°C, M2: 25°C (Source: Christine Eon 2015 audit report)	 D. Inside of window
 E. M1: 47.5°C, M2: 55.3°C, M3: 42.5°C, M4: 33.7°C (Source: Christine Eon 2015 audit report)	 F. Photo of exterior pavement

House H experiences heat gain through the west facing windows. The thermal image of a west facing window in figure 36 shows a massive 13 degree difference between the blind and the wall. An external blind or awning would be an efficient way to shade this window from the afternoon sun and prevent heat entering the house during summer.

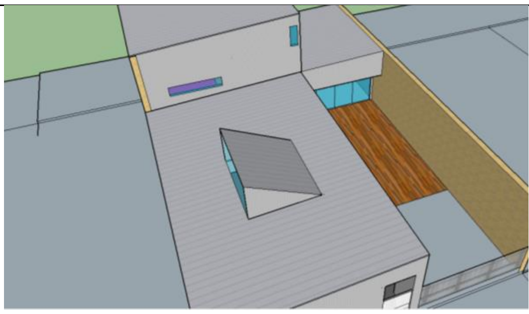
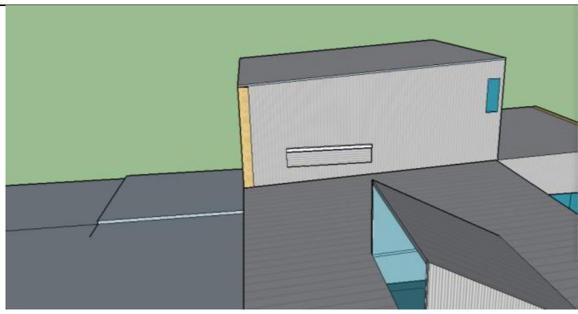


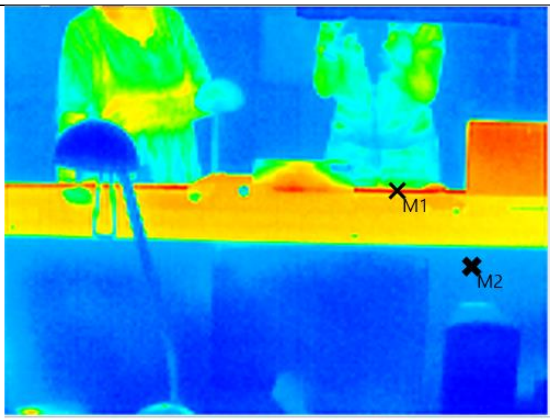
M1: 43.8°C, M2: 30.1°C

Figure 36: West facing window in the afternoon at house H (Source: Christine Eon 2015 audit report)

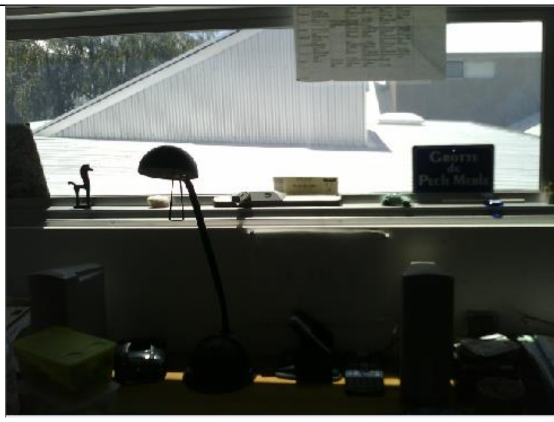
House G is a solar passive designed house that has good thermal performance. One issue is the window on the second floor in front of the study is facing east. So the morning sun hits the window causing the area to heat up very quickly. It stays warm until late evening making the space unbearable unless external cooling is used. Given the window is on the second storey an external roller blind that is able to be controlled from inside would be a better long term solution than a shade sail which would require climbing up on the roof to remove in winter and installing it again in summer. This roller shutter will keep the sun and heat out during the day while allowing it to be wound up and window opened to cool upstairs during the evening. Figure C in table 8 shows the position of the window before and after the solution is applied. Figure B shows the heat difference on the window sill and desk being 16 degrees warmer than the wall out of the direct sunlight.

Table 8 East Facing Window at house G (Google Sketch up models by Luke Murphy)

 A. Sketchup model showing window	 C. Sketchup model showing shutter



B. Thermal image of desk
M1: 44°C, M2: 27.8°C



D. Photo of the area in summer

(Source: Christine Eon 2015 audit report)

House M’s study has West facing windows. The exterior of this facade is unshaded concrete. In the afternoon these west windows are in direct sunlight, which allows heat to enter through the front windows, making it extremely uncomfortable for the occupants. The long term recommendation or solution to provide shade to the exposed concrete is to plant a local deciduous tree such as Fremantle Mallee (Eucalyptus Foecunda), Rottnest Island Tea Tree or a Eucalyptus Platypus which will provide shade to the windows and provide a shady place to sit. Due to it taking a number of years for these local trees to reach a height that would be able to provide sufficient shade a short term solution would be to install a shade sail over the west facing windows to protect them from the sun and fasten the bottom 300-400mm from the base of the window to allow air movement to occur at night to cool the window and allow sufficient light into the room. An example of the design can be seen in figure 37.

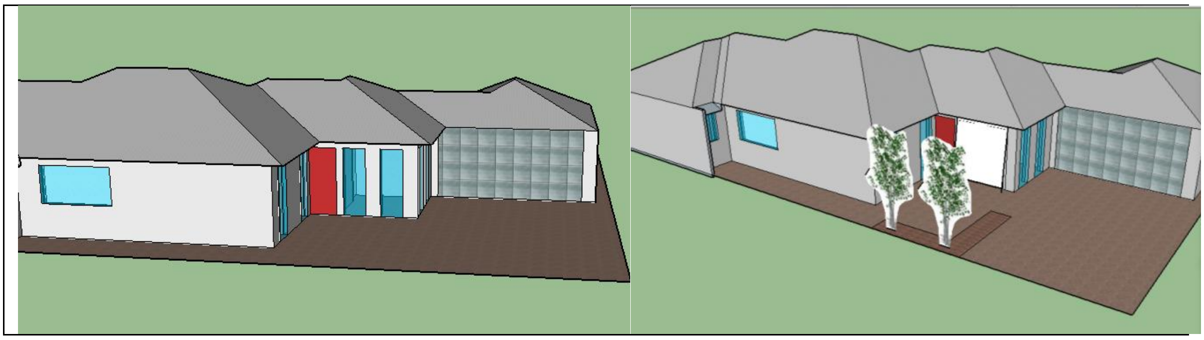
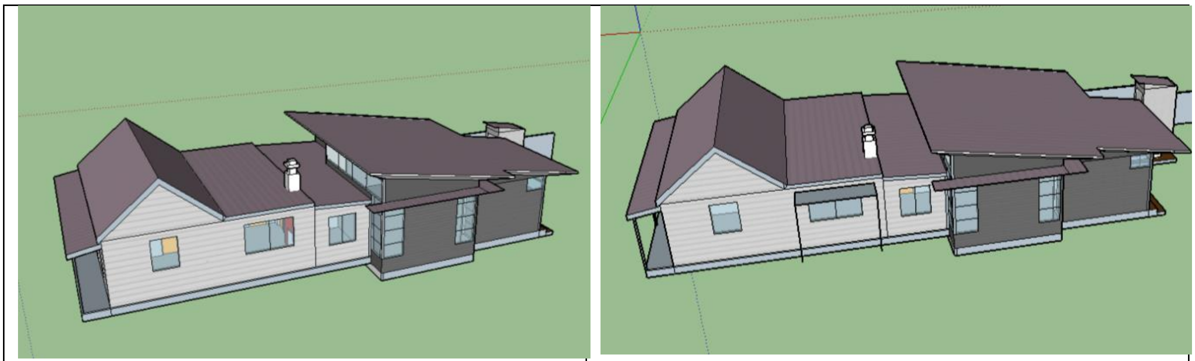


Figure 37: Before and after solution for shading the front room at house M (Source: Luke Murphy Google Sketchup)

Figure 38 shows west facing windows for house P. To decrease the afternoon sun entering through these windows a shade sail should be installed to protect these windows from afternoon sun. These rooms will remain at a lower temperature and the light will still be accessible during winter as a result of removing the shade sail.

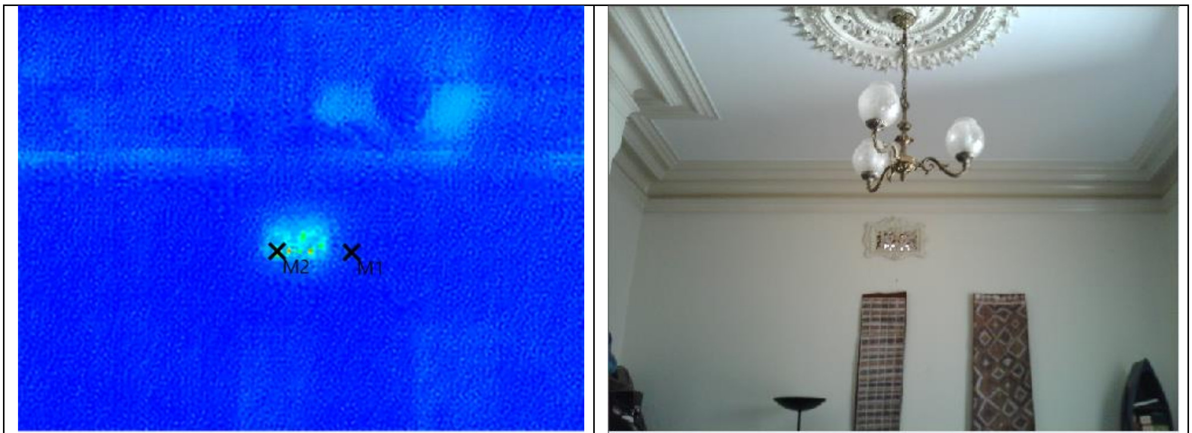


House P model no shading of west windows | House P with shade over west window

Figure 38: West Facing Windows for house P (Source: Luke Murphy Google Sketchup)

Heat gain through old vents

House F contains an old wood fireplace in the pre-existing section of the house, which is not used often due to the new extension now being used as the living room for the house. Figure 39 shows a vent that goes from the old living room straight to the outside of the house. There is almost 10°C difference in this section of the wall compared to the rest of the internal wall. The recommendation would be to seal the inside of the vent with insulation to prevent air movement between the inside and outside of the building while still allowing moisture to leave the cavity.



M1: 27.5°C, M2: 36°C

Figure 39: Wood fire wall vent in the old section of house F (Source: Christine Eon 2015 audit report)

Heat gain through ventilation ducts

An Australian summer can see a ceiling cavity reach temperatures of around 80 °C. If the ducting is not well insulated the air conditioning could be circulating warm air inside. Figure 40 shows the thermal imaging camera visualising heat gain through the vent as the fan was turned on. M1 temperature is 29 °C while M2 is 26 °C, a difference of 3° C. Ceiling fans are a more efficient method of circulating air within the house, compared with ducted fans.

Similarly this can work in an opposite manner in winter as warm air can rise and escape through these vents, and cool air can enter the house from the cooler roofspace, sealing them when not in use is an important method to avoid unwanted heat loss.

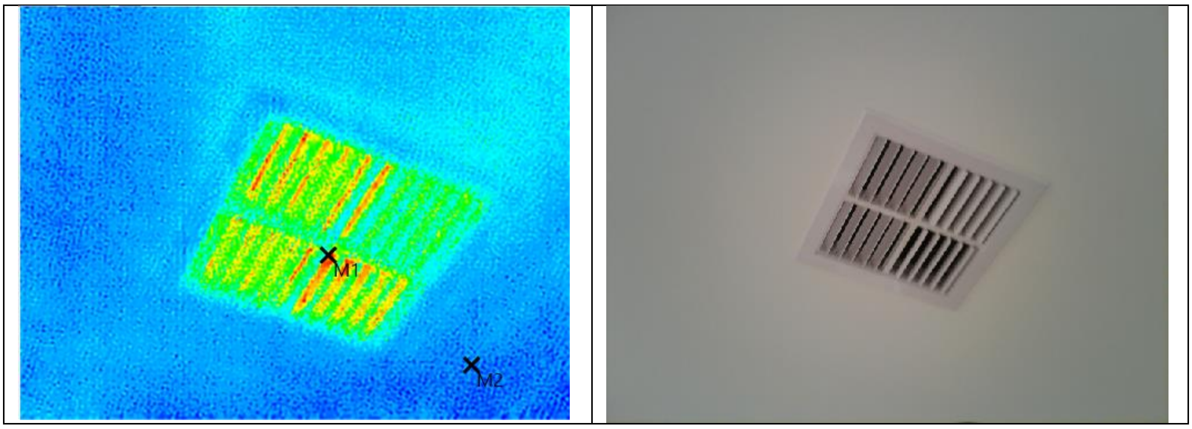


Figure 40: House L ducted (Source: Christine Eon 2015 audit report)

Heat gain through exhaust fans

Bathroom and cooking exhaust extraction fans can enable a large amount of heat to be both gained and lost in winter and summer. A practice to reduce the effect of this is to use a vent cover that opens when the fan is turned on but closes when the fan is switched off. Another way to reduce the air flow into the ceiling is to keep the doors going into the laundry and bathrooms closed when they are not being used so that the air flow through the vents is reduced.

5.2.2 Energy Efficiency improvements

Utilising solar production during the day

With smart technology, common appliances including but not limited to dishwashers, fridges, washing machines and air conditioners are able to be programed to turn on when required. This is an efficient way to utilise solar electricity produced from photovoltaics during the day when occupants are out of the house. All of the energy being used during the day is produced by the sun which means less is required from the grid in the evening. This benefits household’s on the 7 cents per kWh buy back electricity tariff. Figure 41 shows the photovoltaic production during the day and the mains electricity usage. If a portion of the green curve was moved to a time when the PV is at the peak production rate, it will lead to savings on the occupant’s energy bill.

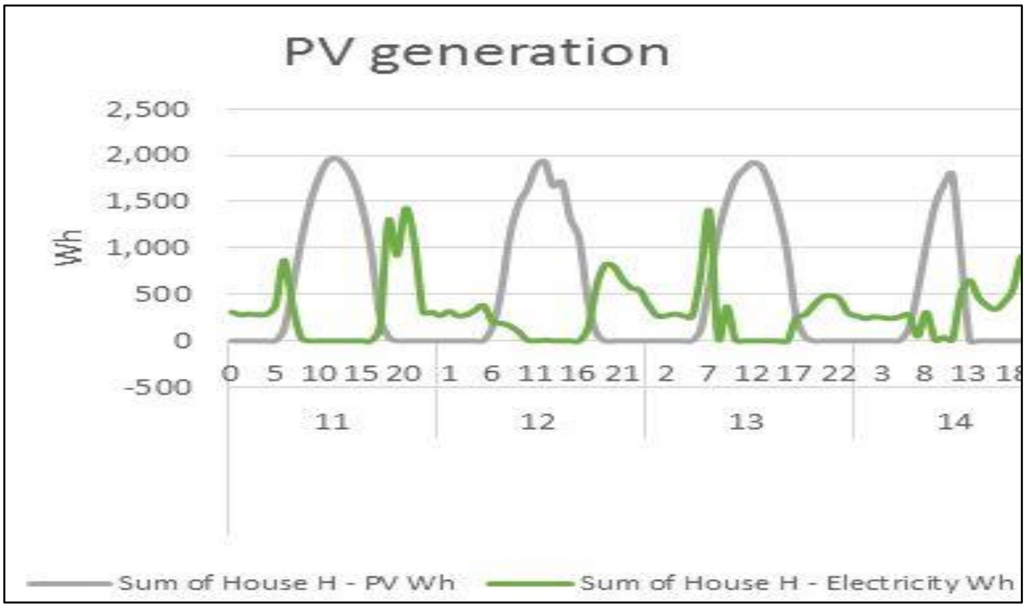


Figure 41: PV production curve against energy usage house H (Source: Christine Eon 2015 audit report)

Another example of behaviours that could influence this change and lead to savings is if the air conditioner is pre-set to turn on at 2pm when it will be powered by the solar panels to pre-cool the house on summer days. This also applies to pool pumps, washing machines and dishwashers all turning on throughout the morning ready for when the occupants return home.

5.2.3 Water Efficiency

House E rainwater tank

The purpose for house E's rainwater tank is for irrigating the gardens and filling their pond. There is an issue with the design where the overflow pipe has a smaller diameter than the inflow pipe. This results in the potential for the gutters to overflow if the outflow tap is not opened prior to heavy rainfall. Meaning that the water tank isn't reaching full potential as rainwater is drained to avoid overflow. The rainwater use measured consists of water leaving as stormwater which doesn't represent main water savings.

To receive the greatest yeild of rainwater per annum with the minimum treatment effort the tank should be plumbed into non-potable sources such as the washing machine or for the use of toilet flushing. House E could enhance this situation by hiring a plumber specialising in roofing to appropriately fit and size the overflow devices for the roofspace. A first flush device should also be installed to capture the dirty water from the roof during the first rain fall event to increase the quality of water captured in the tank.

House G rainwater tank

No Rainwater usage had been recorded for house G for 2 months prior to the first audit. The cause was that the pump had previously burnt out, after being replaced the power switch was left off without being detected by the occupants or the pump installer. No rainwater was being pumped to the toilets or the washing machine even though the tank was full. Before the pump was turned back on the filter was inspected and found to have a film of algae preventing water from flowing through. The occupants weren't aware of any maintenance plan to clean the filter to ensure it is free from blockages. It is assumed that the original pump burnt out due to the increased pressure and workload trying to pump water through a partially blocked filter. If the monitoring software hadn't been available to show the rainwater real time data then it is quite possible the problem wouldn't have been rectified. This incident indicates that the monitoring equipment being used effectively could lead to the occupants identifying and rectifying the problem almost immediately.

House F rainwater Tank

The rainwater tank is filled by a wet feed system. A wet feed system means that the water can be collected from both sides of the roof as seen in figure 42 and the pipes remain full to the level of the outlet pipe. When it rains the water is pushed into the tank. The original system installed didn't have a release valve flush device which resulted in the water sitting in the pipes all summer and then the first winter rain caused dirty water to be flushed into the tank. The water was being used for non-potable use so dirty water flowed into the toilets. By not having an appropriate management plan for the rainwater harvesting system the dirty water entered the household and the whole rainwater tank needed to be emptied and cleaned before it could be filled up again. Now at the end of every winter the release valve is opened and acts as a first flush device to remove the dirt from the roof during the first rains.

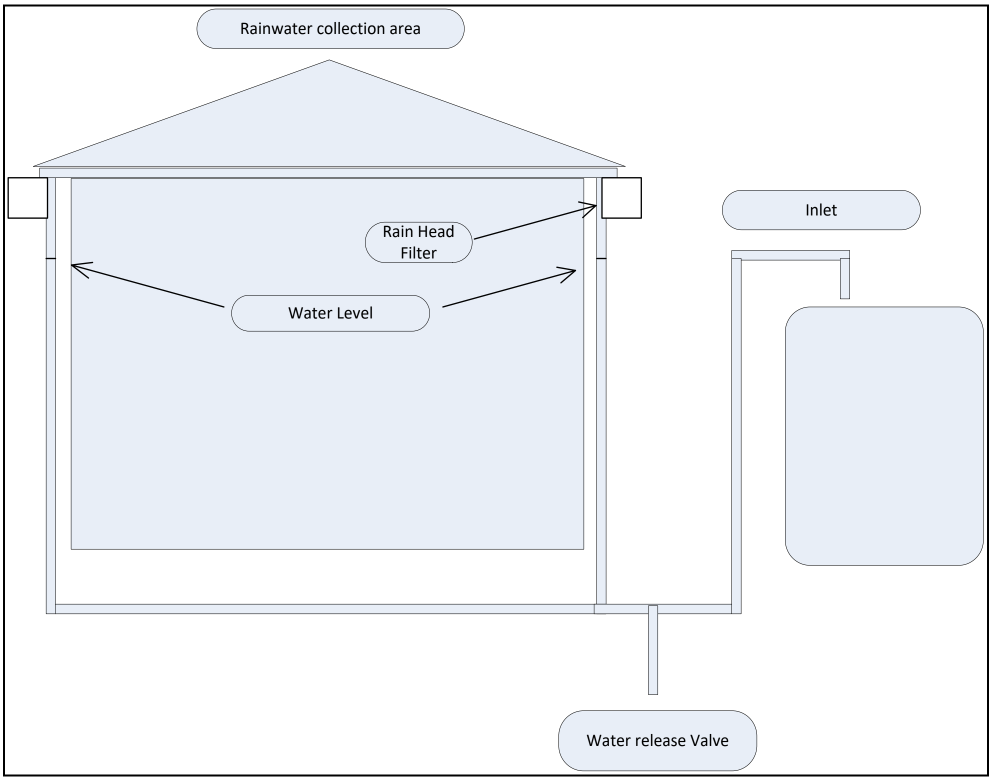


Figure 42: Wet feed rainwater tank design (Source: Luke Murphy)

House H water recycling

House H has a number of innovative water recycling technologies to reduce the mains water demand for both potable and non-potable uses. The occupants have installed two 3 kL rainwater tanks with plans to install a third 3 kL tank to supply potable water to the house to relieve the demand for scheme water. This water is used for showers, hand basins as well as the washing machine. The water from these potable sources are then collected and treated via a Novagrey greywater system which treats greywater produced from the household and reuses this to flush the toilets, feed the washing machine and irrigate the gardens to further reduce the scheme water demand. The Novagrey also recycles nutrients by providing the nutrients to the plants through irrigation. This system allows collection of rainwater to be first utilised in the potable water supply, then reused by a non-potable supply such as a washing machine, and then reused for toilet flushing or irrigation. The business as usual approach is one supply into and out of a dwelling where this house demonstrates recycling water up to three times before it leaves the property.

Even with the water reuse strategy there is not enough greywater produced to fully irrigate the garden so the occupants feel like they aren't as worried about taking long showers because the greywater is being reused on the garden so poor behaviours may be encouraged because the owners may become complacent in using more water than usual.

House E water efficiency

Figure 43 shows that House E has relatively low mains water use, however there is still room for efficiency improvements which can be seen in figure 44. There is a strong correlation between mains water and energy use. This graph indicates that the electric booster is turning on in winter once a large amount of water is used. The possible causes of the high water use could be the shower or washing machine using hot water. Washing in cold water whenever possible and taking shorter showers would not only save energy but also save water. The alternative option would be to replace the inefficient high flow shower heads and taps with low flow efficient options which can also contribute to less energy being used to heat water.

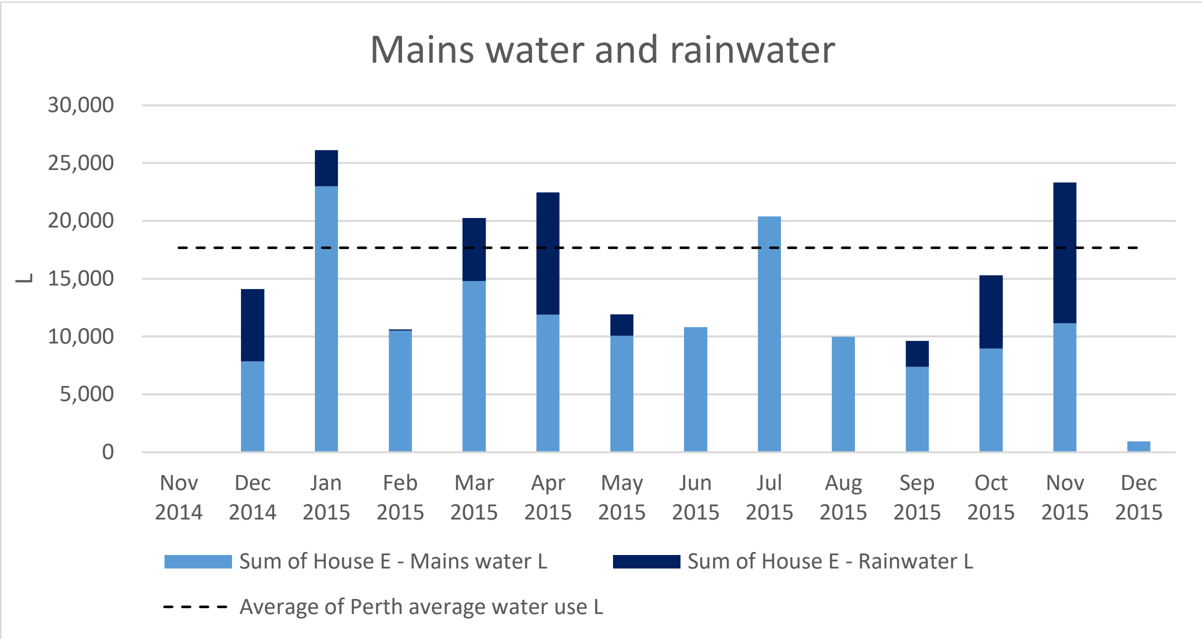


Figure 43: House E Water use (Source: Christine Eon 2015 audit report)

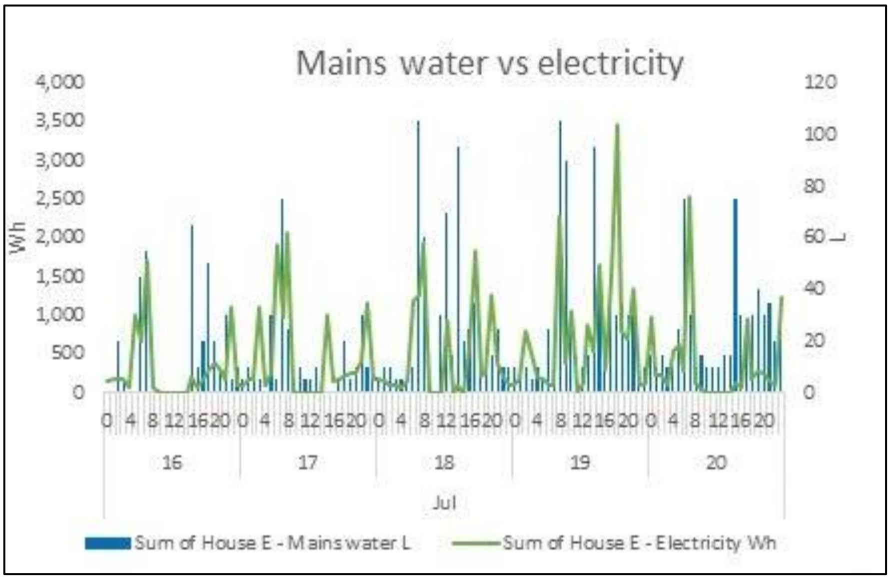


Figure 44: House E mains energy consumption in correlation with main water use (Source: Christine Eon 2015 audit report)

It is found that the occupants are completing a small load of washing every day. Although the washing machine is an efficient front loader that uses 60L of water per wash, it would be more efficient to wash a larger load every few days where possible. In this instance reducing the number of washes from 7 loads down to 4 per week can save 10 kL of water per annum, decreasing down to 3 loads per week can save an extra 3 kL per annum.

5.2.4 Josh Byrne Garden Audit

House B

No garden audit was carried out as there was no behaviour change audit carried out.

House C

The water efficiency for house C is relatively good; however majority of the water use has been used to establish a tree in the front yard. Water use in the garden was further reduced when the vegetable garden was removed.

House E

House E has a good range of water wise plants and the occupants hand water the garden which increases the efficiency of watering. The only notable tip is for when the

House F

House F has a very well thought out garden which is hand watered. The lawn was replaced with recycled carpet to further reduce the water demand and maintenance requirements.

House G

The garden at house G is extremely water wise with a small amount of lawn and native coastal plants. The only tip to note is to check the irrigation periodically.

House H Garden Maintenance

Given there is a large amount of lawn at the back of this house, summer water use can be reduced by replacing the front lawn with coastal native shrub species which would require no water once established. In addition heavy traffic areas on the back lawn can be repaired by aeration and top dressing with a nutrient rich soil to reduce the water requirement.

House L

The occupants have a great practice of hand watering instead of reticulation their garden which consists of a wide variety of plants. The only notable change would be to apply mulch to the gardens to reduce the water requirements of the garden.

House M

House M consists of a large portion of concrete pavers with small gardens around the house. The plants water demand would be decreased by applying a layer of mulch.

House O Garden Water Efficiency

House O currently has surface sprayers installed for its irrigation requirements. It was noted that a more efficient method of irrigation would be Beta Film driplines which are subsurface drippers that provide water directly to the roots of plants to reduce loss from evaporation and wind drift. Another recommendation was to install a hunter X-core weather controller to detect the weather conditions and adjust to any rainfall that might occur automatically. This will save water from being wasted when the plants have enough water already available.

Appropriate plant choices in the right area can assist the efficiency and liveability of the home. Choosing plants that are native in the area means they are likely to be able to thrive with very little excess water as well as providing shading to the surrounding ground or house making the climate cooler and more attractive without using great amounts of water. Some water wise plants for the driveway includes Dianella Seascape, Grevillea Seaspray (foam Foliage and Lomandra Longifolia Tamakas and to cool the side of the house Chinese Star Jasmin can be used as a creeper. The previous plant choices have struggled with the lack of nutrients and heat from the driveway.

House P

House P’s garden water requirement was increased with the installation of lawn in the backyard which is used for a play area. The sprinklers are a water efficient model, however to reduce the wear in certain patches top dressing the lawn would be beneficial to keep the water requirements to a minimum.

5.2.5 Renewable Energy

Photovoltaic System

An interesting part of the study was receiving feedback that the occupants for house C utilised the monitoring equipment to see how much of an effect washing the photovoltaic solar panels has on increasing energy production. The occupants could see an increase in production on the monitoring website and felt that cleaning the solar panels was a proven benefit to them.

House H had a period where there was no solar production from the 2kW Photovoltaic system. Once it was analysed on the monitoring equipment the occupants were notified and further investigation took place which found that the systems power had tripped. The monitoring equipment registered it had tripped around midday on the 14th of November with heavy rain being the assumed cause. The observation is shown in figure 45 where the solar PV registers zero while electricity continues to be used.

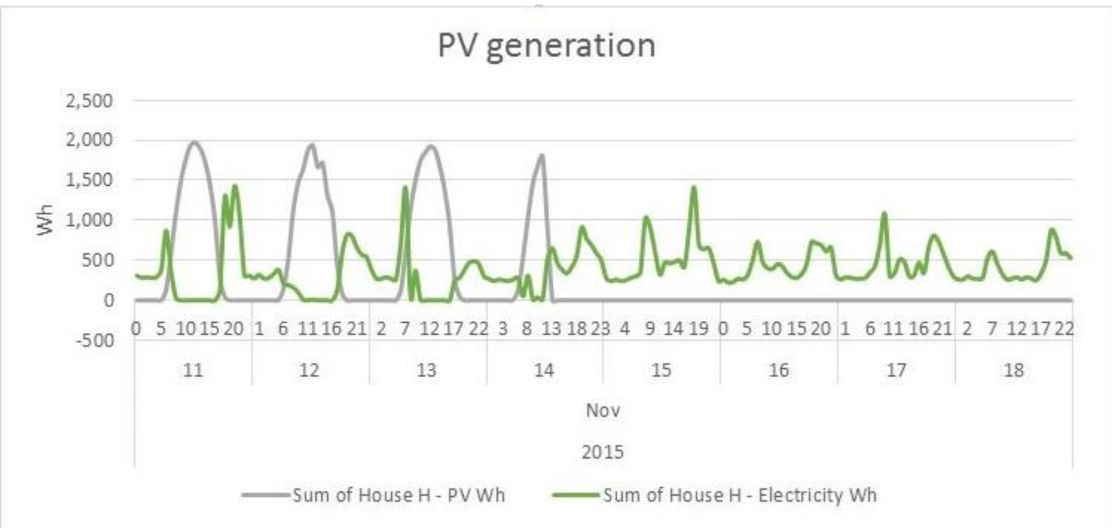


Figure 45: House H PV from the 11th November to the 18th of November (Source: Christine Eon 2015 audit report)

Figure 46 reiterates that another fault occurred that was picked up with the comparison showing when working the system is producing more electricity than the other houses. It appears the system was switched back on around the 8th of October and tripped again on the 14th of October. Every time the PV system trips the occupants loose free energy and have to draw more from the grid reducing the efficiency of the system. It would be beneficial to identify and fix the problem so no more potential savings are lost.

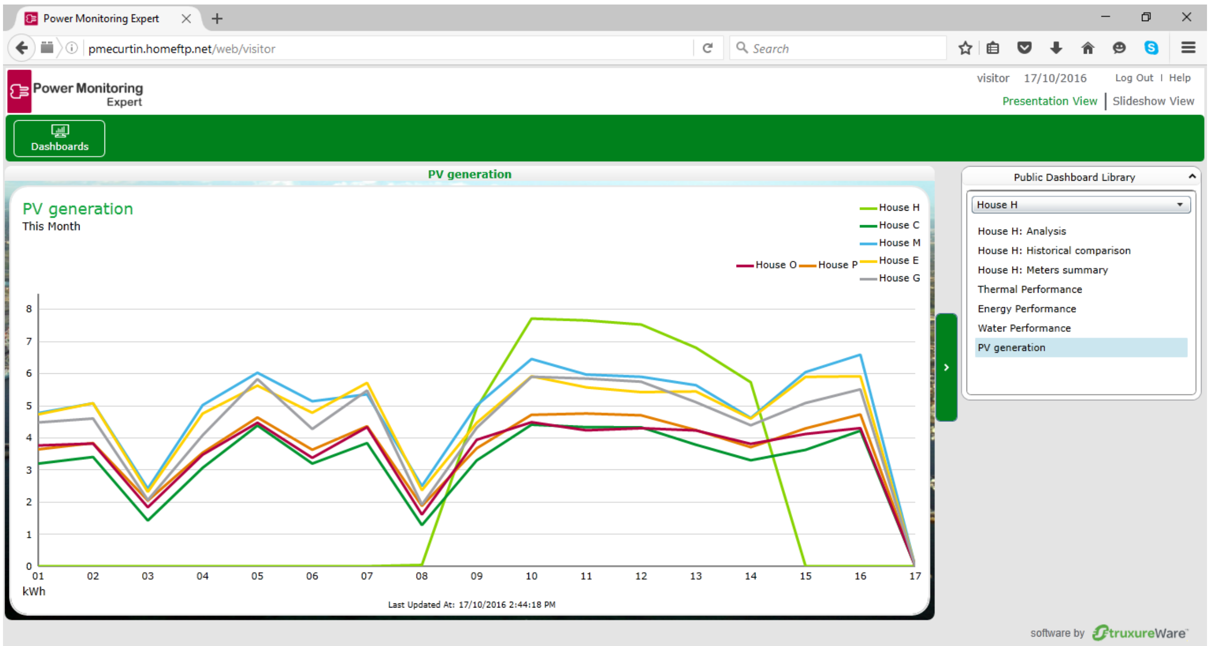


Figure 46: House H monitoring website showing PV system performance in October 2016. (Screenshot taken from http://pmecurtin.homeftp.net/web/ on the 17/10/2016)F

Solar Hot Water Systems

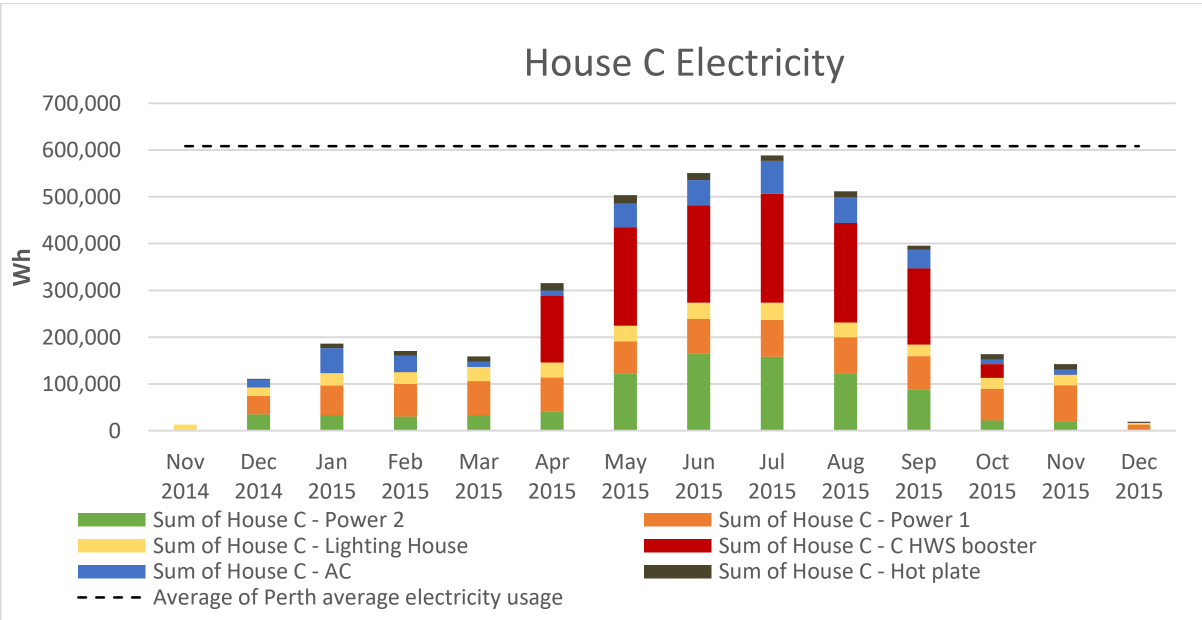


Figure 47: House C electricity consumption breakdown (Source: Christine Eon 2015 house audit report)

For house C, electricity data was collected for the major appliances including the lighting, air conditioner, two separate power circuits, the hot plate and the Hot water system electric booster. Figure 47 shows that in winter the hot water system booster electricity consumption increases massively with a small increase in the power 2 circuit. Upon further investigation the main cause for this increase in electricity is the hot water system is shaded in winter due to trees blocking the sun, as well as bar heaters located in the kid's bedrooms during winter.

Behaviour efficiency for Gas boosted solar hot water system

House M uses gas for cooking as well as a booster for the solar hot water system. From Figure 49 it can be seen that the gas usage is much greater in winter than summer. The solar collector plates are on an east facing roof which is seen in figure 50 where a tree shades the panels from the morning sun. It is assumed that not enough sun is able to heat the panels in winter. Figure 51 shows the correlation between water and gas. From this graph the green bar indicates rainwater being used at the same time as the gas peaks. This indicates hot water could be used when doing laundry as well as for showers. There is inefficiency caused by poor placement of the hot water collectors. However behaviours including washing with cold water and having shorter showers would decrease the amount of gas required to maintain hot water.

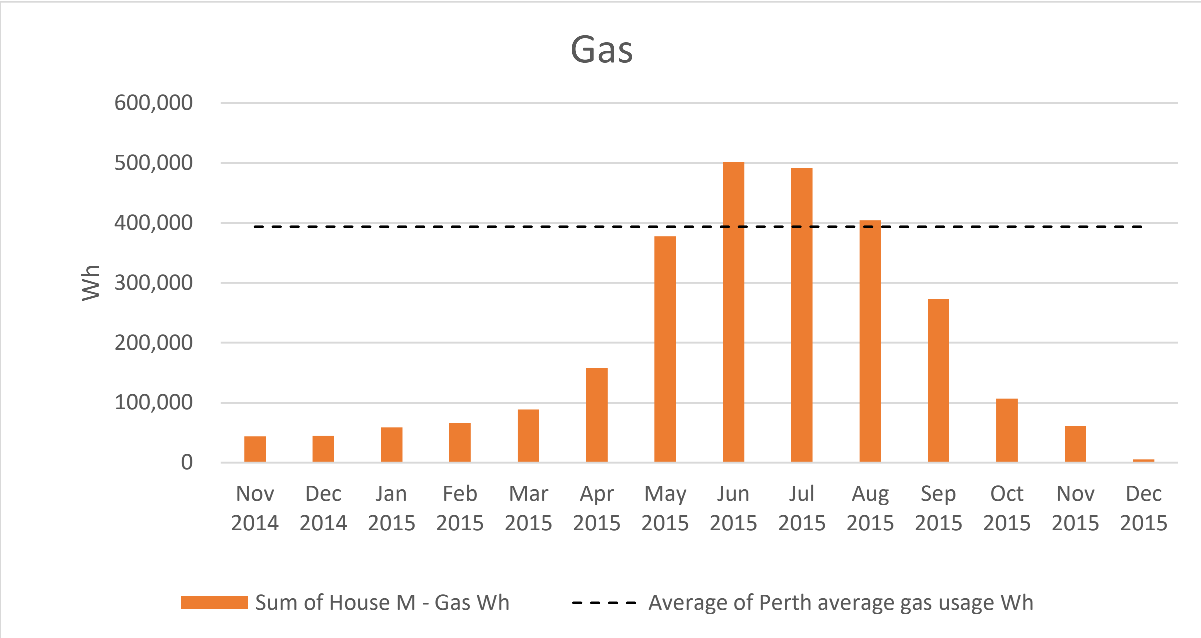


Figure 48: House M gas use for 2015 (Source: Christine Eon 2015 audit report)

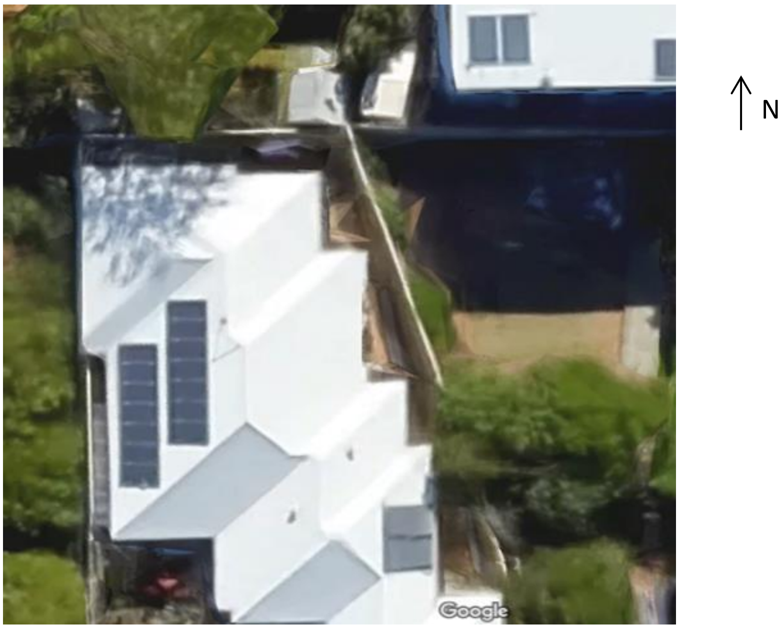


Figure 49: House M with solar collectors positioned so shaded by the tree to the east (source: Google Earth, 6/11/2016)

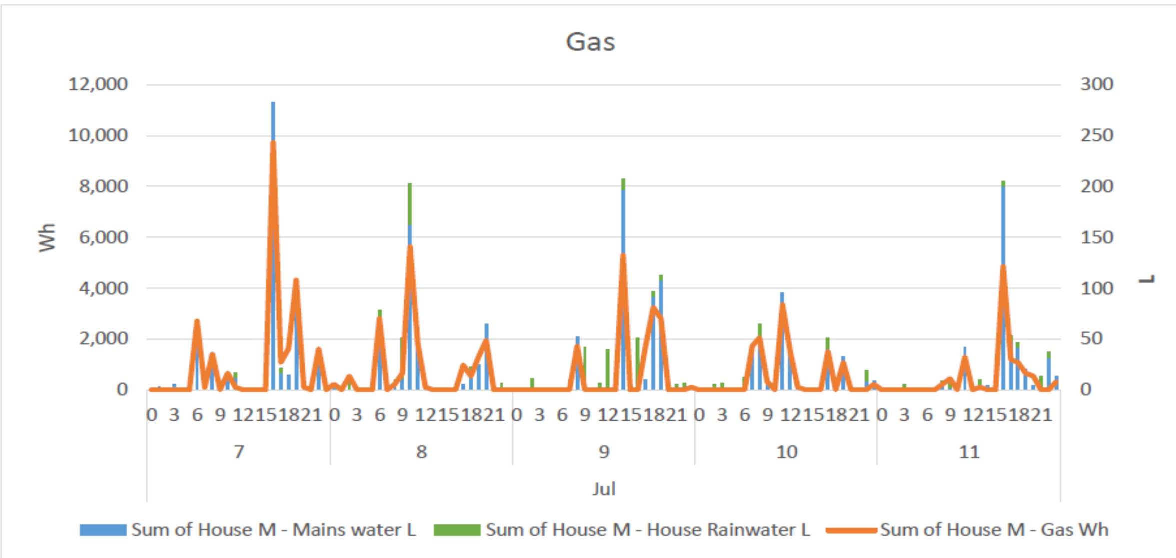


Figure 50: house M gas use in correlation with water use (Source: Christine Eon 2015 audit report)

House G chose to install an instant gas hot water system instead of solar hot water system. Figure 52 shows the gas use is spread across the year with it being slightly higher in winter which is assumed to be due to longer showers as well as more energy being used to overcome greater temperature differences. The gas use for house G is slightly higher in summer than at house M, but it remains lower than house M in winter, which reiterates the inefficiency of house M's system due to poor placement. Figure 53 shows the correlation between water and gas use which reiterates that reducing shower time will result in a reduction in gas use.

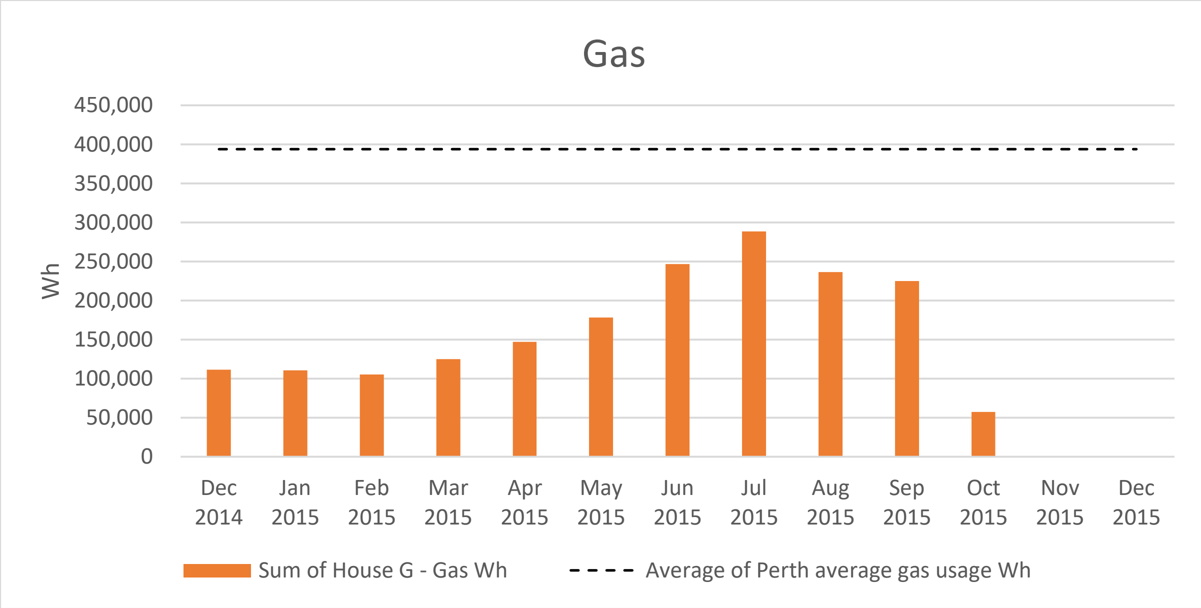


Figure 51: House G gas use for 2015 (Source: Christine Eon 2015 audit report)

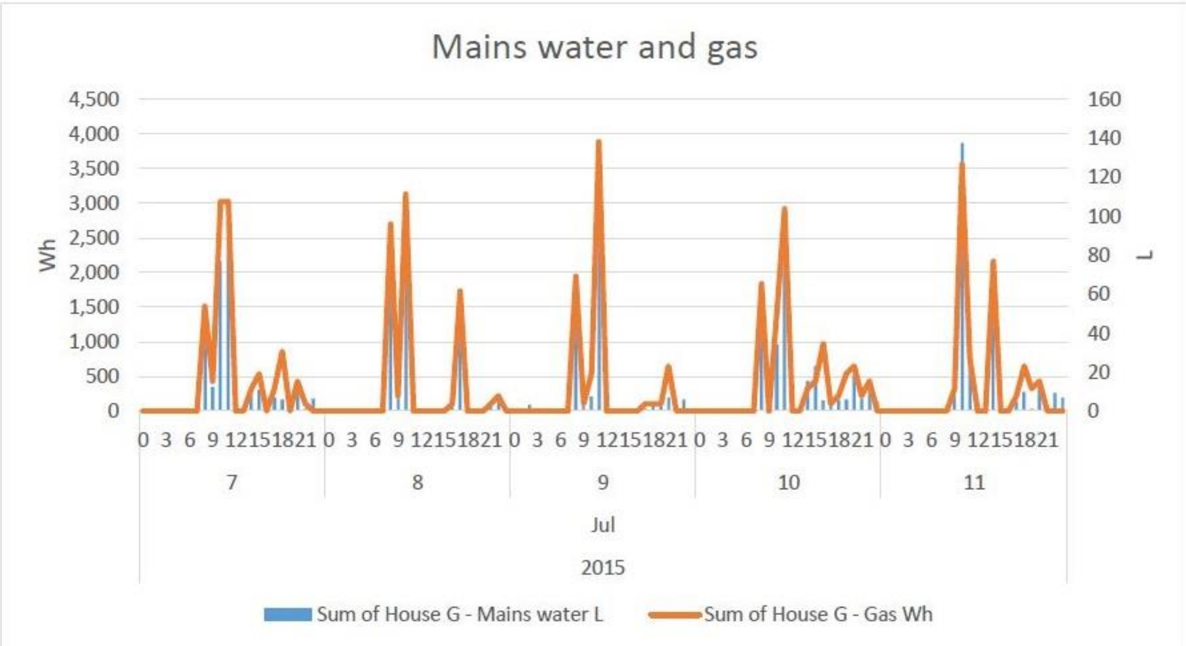


Figure 52: Gas correlation with water use (Source: Christine Eon 2015 audit report)

5.2.6 Summary of efficiency improvements applicable to multiple dwellings

1. Shading east and west facing façades during summer, especially windows
2. Replace energy inefficient globes with efficient LED globes
3. Turn appliances off at the wall to reduce standby power usage when able
4. Utilise thermal mass to store night time coolth for during the day
5. Ensure insulation covers the entire ceiling to prevent unwanted heat transfer
6. Turn air conditioning to above 24 degrees Celsius and heating below 24 degrees Celsius
7. Using ceiling fans as an efficient, alternative form of cooling than an air conditioner

8. Reducing shower times and replacing inefficient shower heads with a higher star rating will save both mains water and energy
9. Washing clothes in cold water instead of hot water will save on water heating requirements of the house
10. Mulch gardens to reduce evaporation from the soil

6.0 Conclusion

In relation to objective I, the full lifecycle assessment for the 10 houses was successful in providing an assessment of the sustainability and carbon footprint associated with each house. By comparing the carbon footprint of the materials for each house it was identified that the embodied energy could be reduced by using timber frame cladded walls or reverse brick veneer instead of the traditional double brick construction. Operational energy reduction methods can include using LED lighting instead of CFL or Halogen lighting types or utilising ceiling fans over air conditioning wherever possible.

It was also found that in relation to objective II, certain behaviours cause an increase in the operational energy of the house such as taking longer showers, washing clothes with hot water and not utilising appliances during solar production hours. However there are certainly some housing efficiency improvements which relate to objective III that were identified in this study which could apply to houses specifically in Perth. Practices such as shading external east and west facing windows with external blinds or by trees, ensuring walls and ceilings are insulated correctly, replacing high flow fixtures with more efficient low flow models and maintaining solar panels and rainwater tanks are some of the ways a house can be made more efficient to reduce the operational energy of the house and encourage energy efficient behaviours.

Monitoring equipment that displays the real-time data directly to the occupants can be a great way to help influence efficient behaviour or identify any inefficiencies caused by faults, leaks or inefficiencies around the house which in turn can lead to savings for the house. With smart technology this option can be implemented to both new and old houses.

In relation to objective IV, to improve the sustainability of the housing market in Australia a life cycle assessment way of thinking will contribute to a reduction in the carbon footprint of houses. By employing a LCA tool alongside the existing NatHERS star rating, houses will obtain a measurement of all aspects of the life cycle carbon impacts of a building which includes the embodied and operational impacts such as heating and cooling, lighting, hot water heating, refrigeration and entertainment requirements.

For existing housing an analysis is required between the actual measured data and the predicted data to help identify areas of improvement for both behaviour change and house efficiency changes. This information can form part of an energy performance certificate for the owners to rectify the identified areas which will ultimately save energy, water and gas and reduce operational costs for the occupants.

Future work that could be considered which is outside the scope of this thesis is to consider the recommendations and use eTool to design a lower carbon footprint house while also taking into consideration the cost and liveability compared to the usual building construction methods.

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8.0 Appendices

Appendix A: Google Sketch up models

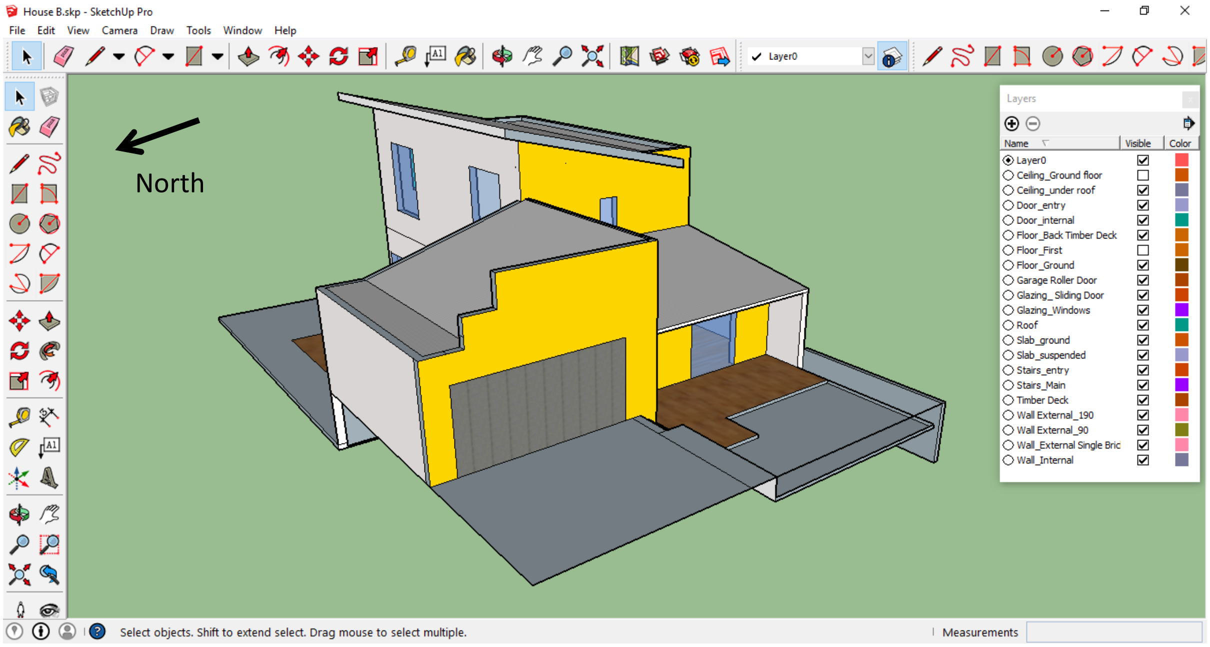


Figure 53: House B google sketch up model with layers used (Google Sketch up models by Luke Murphy)

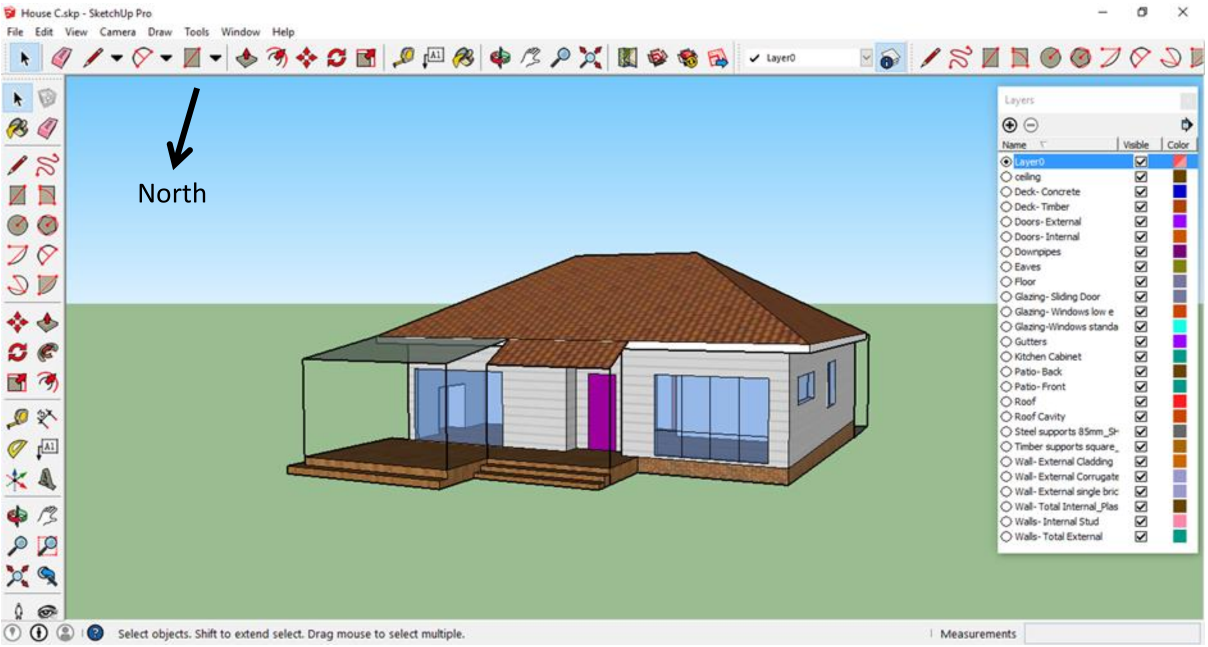


Figure 54: House C Google sketch up model with Layers used (Google Sketch up models by Luke Murphy)

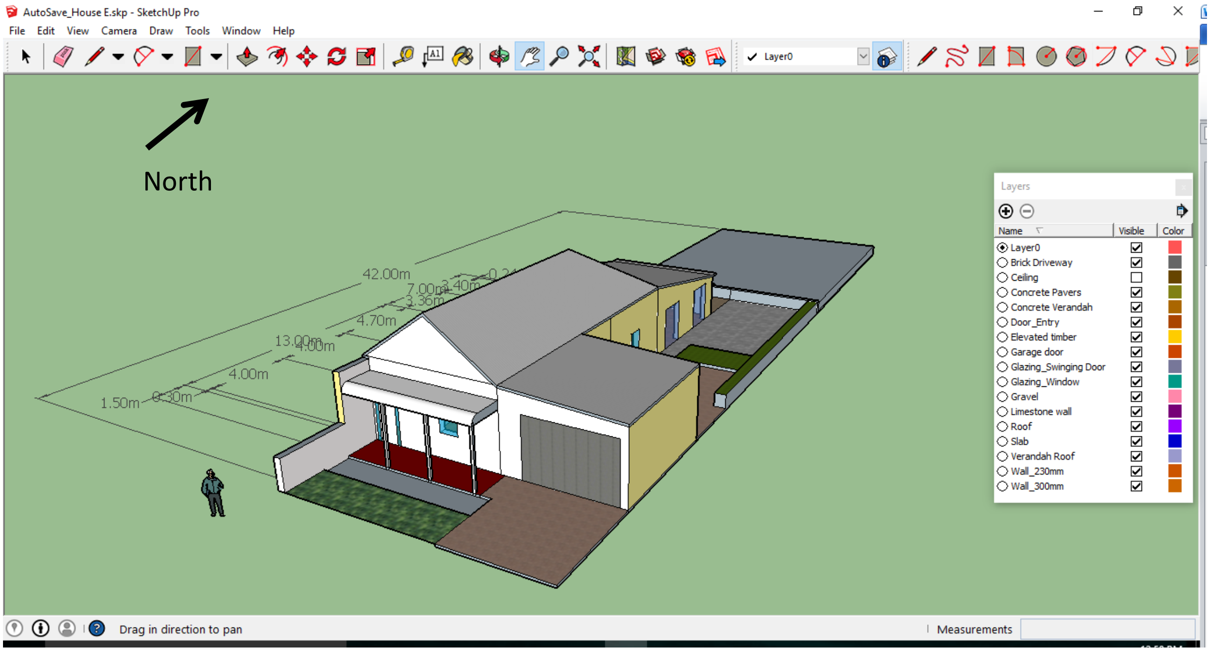


Figure 55: House E google Sketch up models with layers used (Google Sketch up models by Luke Murphy)

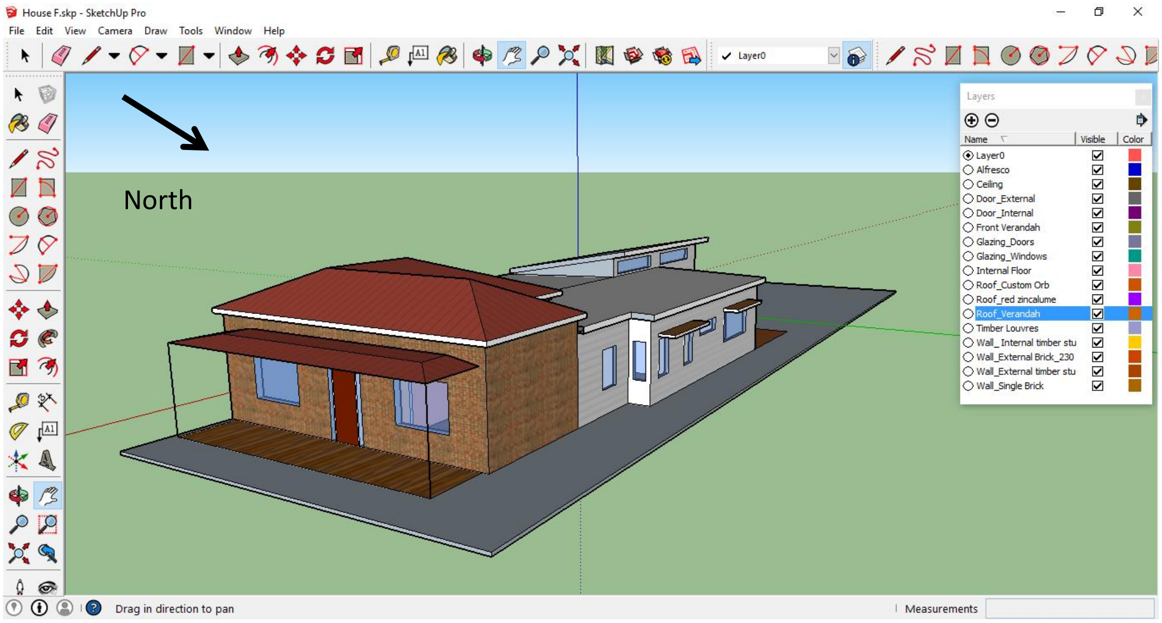


Figure 56: House F google sketch up model with layers used (Google Sketch up models by Luke Murphy)

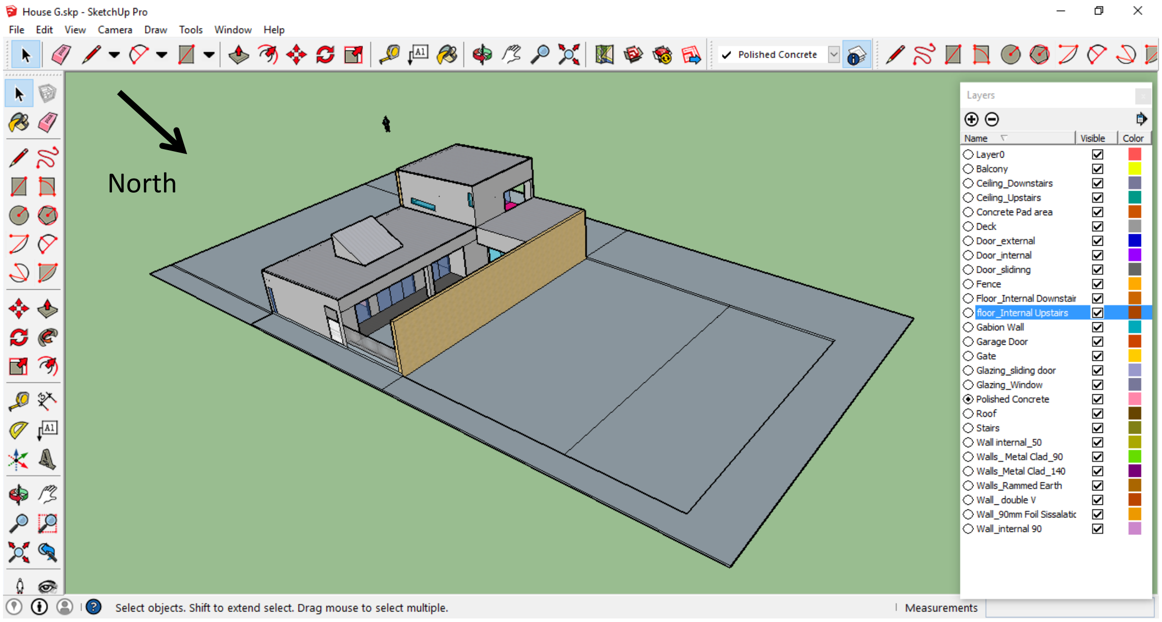


Figure 57: House G google sketch up model with the layers used (Google Sketch up models by Luke Murphy)

Figure 58: House H google sketch up model with layers used (Google Sketch up models by Luke Murphy)

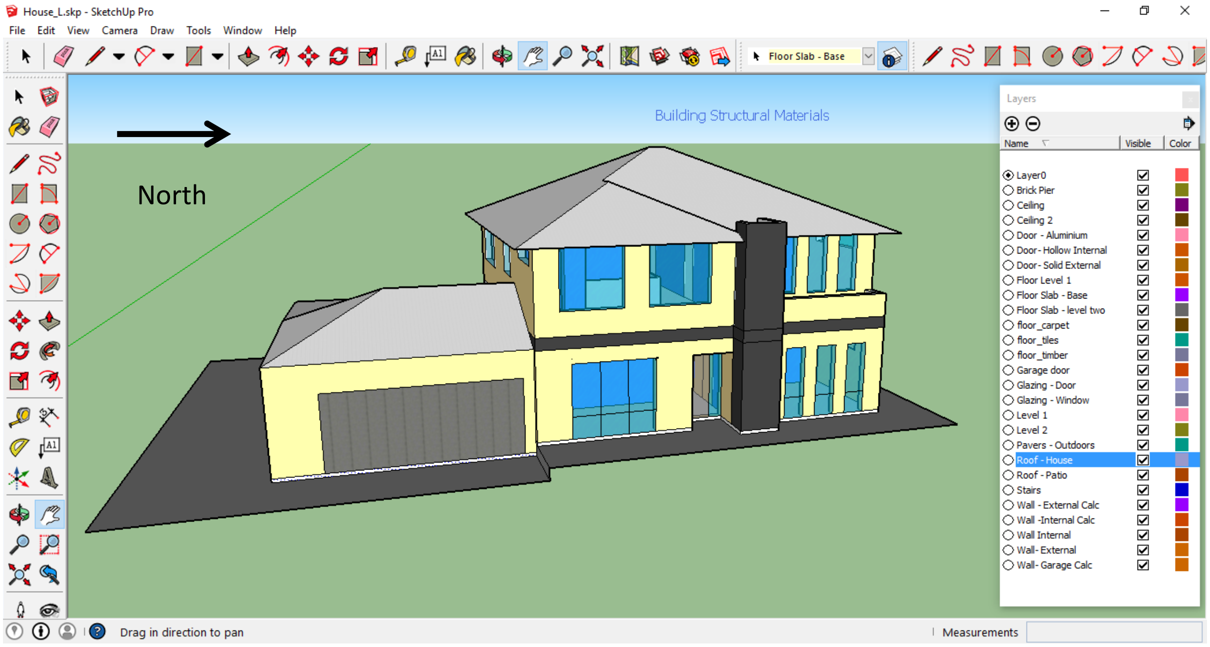


Figure 59: House L Google Sketch up model with layers used (Google Sketch up models by Luke Murphy)

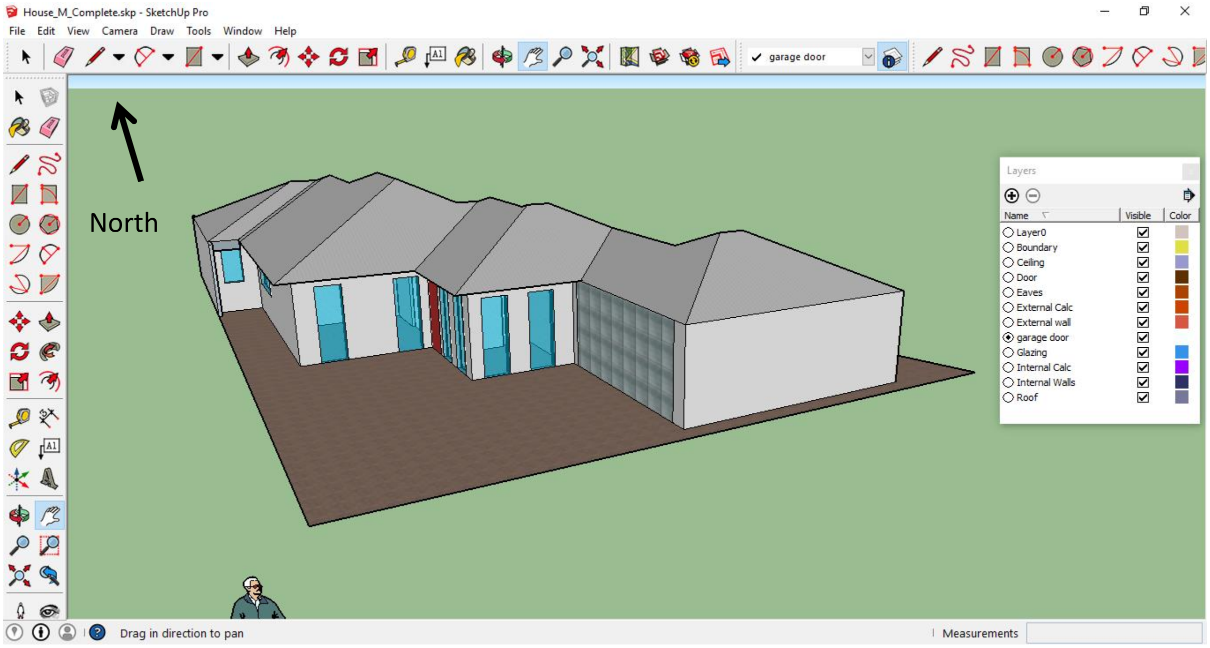


Figure 60: House M Google Sketch up model with layers used (Google Sketch up models by Luke Murphy)

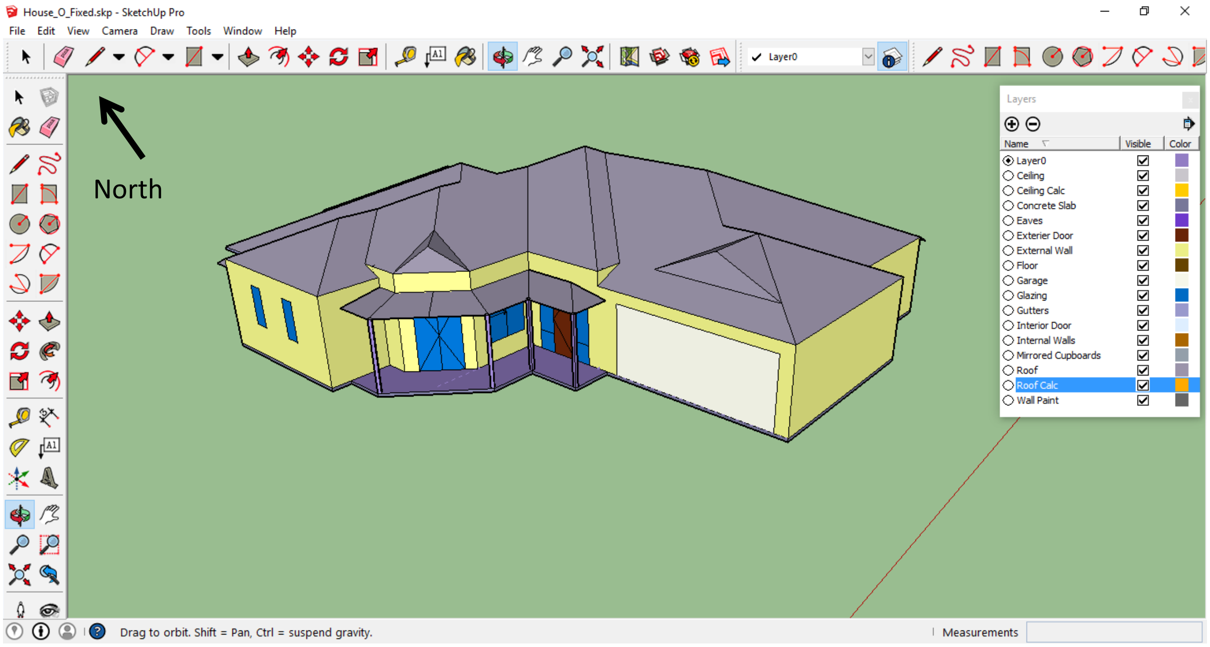


Figure 61: House O Google Sketch up model with layers used (Google Sketch up models by Luke Murphy)

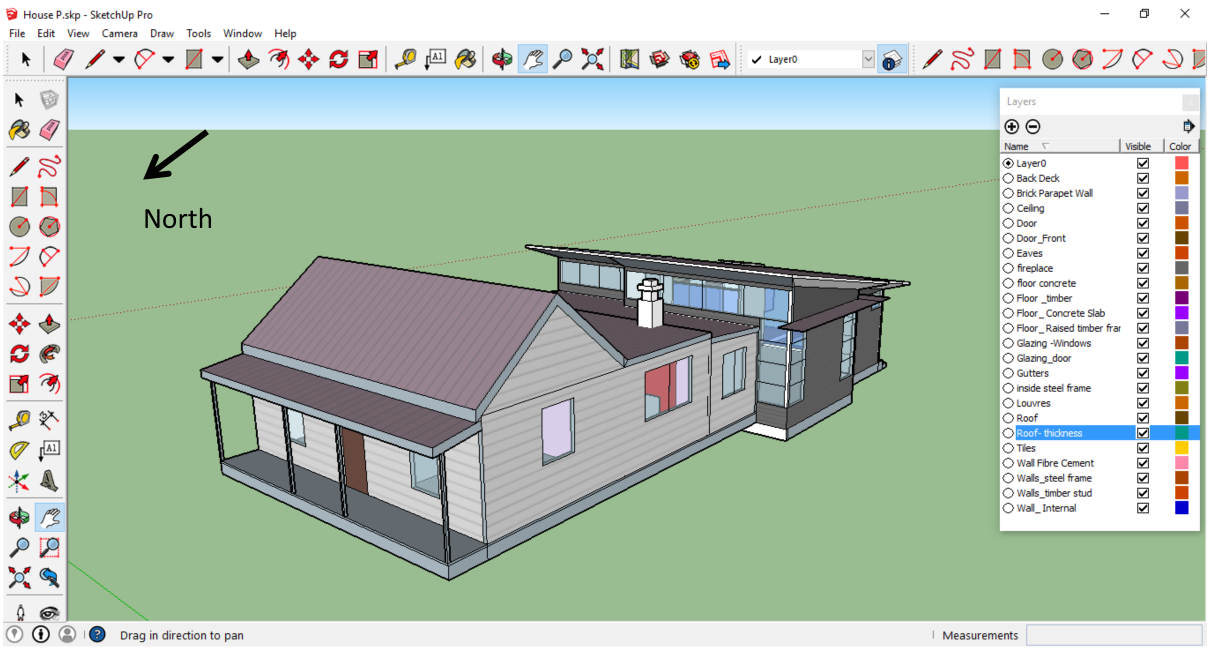


Figure 62: House P google Sketch up model with the layers used (Google Sketch up models by Luke Murphy)

Appendix B: Material offtake and eTool Specifications for each house

Table 9: House B, 8.5 stars, NatHERS thermal rating 15 MJ/m^2

	m^2	Comments		
Overall Area	273	Taken from google sketchup drawing (block Size)		
Internal Floor area_Ground	104	Taken from sketchup (different levels of ground floor)		
Internal Floor area_First	51	upper level		
total internal	162.6	Heating & cooling load		
Concrete Pad ground	122	100mm slab on compacted fill		
Concrete Pad Raised	63	upper level		
Roof Area	145.75	tin area		
Ceiling Area_First Floor	136.5	under roof		
Ceiling Area_Ground Floor	51.35	Taken from sketchup		
Wall_ Internal area	156	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ External Area	259	(external walls including double layer)		
Windows-Glazed Areas	25	Windows and glass doors all single glazed (aluminium Frame)		
Door-Glazed	21	4		
Door External	3.7	2		
Door Internal	13	8		
Stairs_entry	2.6			
Stairs_main	5			
Floor- Total	162.6	from plans		
Floor_Carpet	43	sketchup (bedrooms)		
Floor-Tiles	14.45	Bathroom/ toilet/ Laundry		
Floor-Timber Floorboards	21.65	stairs and front room		
Floor-Polished Concrete	43	living room		
Floor-Painted	32.67	garage		

Concrete				
timber front deck	15.75			
timber back deck	53.5			
timber balcony	3			
Internal Paint	312	selection including all internal walls from sketch up		
External Paint	126.01			
Lighting				
Mechanical Ventilation	0			
Thermal Demand	15MJ/m^2			
Lighting Run time	730hrs/y	1.4hrs per day		
Lux	150	min building code		
PV	1 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	3	Exhaust extraction fan, steel		
ceiling fan	4	HVAC Residential Ceiling Fans		
HWS	1	Solar with gas booster		
RW tank	4000L	with pump		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof	Timber Truss ()	Roof - TimberTruss/SteelSheeting/10°Pitch/RakingCeiling/Insulation	145.75	m^2 (pitch accounted for)
Ceiling first floor	Plaster	Ceiling - Plasterboard+paint	51.35	m^2
External Walls	Brick 230mm	Double Brick Cavity Wall (90-50-90) render ext plaster int	259	m^2
Wall insulation	reflective foil insulation to east and west facing walls	Insulation - Foil Sisalation (wall)	73	m^2
Internal Walls	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior	156	m^2
Floor-Concrete Pad (living Room)	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	122	m^2
Elevated concrete slab	1% reinforcement, 30 MPa.	Floor, 200mm elevated slab	63	m^2
Floor_Carpet	Carpet over concrete slab	Floor Covering - Carpet (glue down/Nylon)	43	m^2
Floor-Tiles	Tiles	Floor Covering - Tiles (ceramic/5mm)	14.45	m^2
Floors-	Timber 25mm	Polished Timber floor - Glue Down	21.65	m^2

Timber				
Floor-Polished Concrete	polished/ coating	Floor Finish - Grind+PU Coated Polished Concrete (PU coating adjusted)	43	m^2
Floor-Painted Concrete	coating	Floor Finish - Coloured Epoxy Concrete Floor Coating	32.67	m^2
Floors-back deck	Timber decking	Floor, wooden decking, elevated on steel anchors	53.5	m^2
Floors-front deck	Timber decking	Floor, wooden decking, elevated on steel anchors	15.75	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	1 kW	
Doors-External	Timber	Door, Solid Core and Steel Jam (Entry)	3.7	2
Doors-Internal	Timber	Door, Hollow Core and Steel Jam	13	8
Door-sliding	glass sliding timber frame	Door, commercial sliding glass with hardware	21	4
Windows	Aluminium Frame	Windows, Residential Aluminium Single Glaze, fly screen	25	m^2
Stairs-garage	concrete base	Staircase, Concrete (40Mpa, 2% reo) + timber steps	0.5m rise	
Stairs-Entry	concrete base	Staircase, Concrete (40Mpa, 2% reo) + timber steps	1m rise	
Stairs-Main	concrete base	Staircase, Concrete (40Mpa, 2% reo) + timber steps	3m rise	
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower/ toilet	Standard Large Bathroom - WC/Bath-Shower/Basin*2/WallTiles	1	
Powder room	toilet/ basin	PDR	1	
Lighting-CFL	50% of building	Lighting Residential CFL High Natural Light		
Lighting-LED	25% of building	Lighting Residential LED High Natural Light		
Lighting-Halogen	25% of building	Lighting Res 12V Halogen High Natural		
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection, Residential		
gas connection		Gas Connection (single dwelling)		
HWS	HWS - solar w electric booster	HWS - Solar Thermal + Gas Boost (240L) + Low Flow Showerheads	1	
2 Rainwater tank	steel	Rainwater tank - steel (embodied)	2	
electric pump for RW tank		Electric Pump	0.8kW	
electric pump				

As-Built				
Water use		Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em		
With actual Appliances				
Additional appliances	**Energy/Water/ Gas**	**Etool Assumption (template)**		
	Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em		
	oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		
	Water Supply	Average Water Use & Treatment WA/AUS (no pool)		

Table 10: House C, Assume 6 Star Equivalence NatHERS thermal rating 39MJ/m^2

	m^2	**Comments**	
Overall Area	510	total area from google earth (Excluding Granny Flat)	
Internal Floor area	96	heating and cooling	
Fully Enclosed Covered Area	96		
Roof- Front Deck	12.45	See Through Perspex	
Roof- Back Patio	20.96	corrugated iron	
unenclosed covered area	33.41		
Total Usable Area	129.41	eTool input	
Roof Area	161.52	Sketchup pitched area	
Ceiling Area	119	including Eaves (horizontal area)	
Internal Wall Area Total	223	timber stud wall	
External Wall Area Total	111.5	mixed materials	
Wall- External Cladding	63.84	outside wall	
Wall- Single Brick	24.92	under house	
Wall- Corrugated Iron	30.55	back outside wall	
Wall- Internal Stud	111.5	divided by 2	
Glazed Window	15.6	low e glazing	
Glazed- Sliding Door	6	patio	
Total Door Internal Area	7.9	5x	
Total Door External Area	3.3	2x	
Floor- Total	96	Elevated Floor	
Floor- Timber Floorboards	96	Elevated timber floorboards	
Floor- Front Deck	50.74	Timber	
Floor- Back patio	22.4	Concrete pavers	

Internal Paint	223		
Lighting	69.83		
Mechanical Ventilation	0		
Thermal Demand	39MJ/m^2	assumption of a 6 star home given all the retrofit upgrades	
Lighting Run time	730hrs/y	2hrs per day	
Lux	150	min building code	
PV	1.5 kW	Solar PV system - zone 3 Perth	
Etool Masterial Inputs & assumptions			
	Structure	**Etool Assumption (template)**	**Measurement**
Roof	Timber Truss (30° pitch)	Roof - TimberTruss/Clay tile/25°Pitch	119 m^2 Horizontal 161.5 m^2 rake
Roof- Front Patio	Timber Posts	covering- clear PolyCaarb Sheeting (Corrugated) Posts/ beams	12.45 m^2
Roof - Back Patio	Steel Posts	Covering- Steel Sheeting 0.42mm corrugated	20.96 m^2
Ceiling	Plasterboard (12mm)	Roof - TimberTruss/Clay tile/25°Pitch	119 m^2
External Walls_Cladding	Timber Stud	timber stud Ext Wall- FC/WB Clad & PB	63.84 m^2
External Walls_Corrugated Iron	Timber Stud	timber stud Ext Wall- FC/WB Clad &PB (FC/WB removed) +Wall Cladding- Includes Internal Paint finish	30.55 m^2
External Walls_ Brick retaining	Single brick	Insulation/ Rigid Foam/ Polyethylene	24.92 m^2
Internal Walls	timber Stud	12mm Plasterboard Timber stud frame (600mm to centre) Paint (industry standard) Rockwool Bulk insulation	111 m^2
Floor- Front Deck	Timber	Floor, Wooden Decking, Elevated on steel anchors	50.74 m^2
Floors- Back Patio	Concrete	Concrete Floor - 100mm slab on ground/ 30MPa/ 1 % Reo/ no fd	22.4 m^2
Floors- Internal	Timber	Floor - Elevated Timber Frame	96 m^2
Kitchen	Timber cabinets	Kitchen Cabinetry Medium	1
Bathroom	Timber Cabinets, Concrete floor	Standard 1st Bathroom - WC/ Shower/ Sink/ Wall tiles	1
Laundry	concrete floor, steel cabinet	Standard laundry Sink)Steel) + Services	1
Doors	Timber	Door, Solid core and steel jam	7 Doors
Windows	Aluminium Frame	Windows single glazed aluminium frame individual components	15.6 m^2
Sliding doors	Aluminium Frame	Door, Commercial sliding glass with hardware	6 m^2
Lights - LED	50%	Lighting Residential LED Med Natural light	10
Lights -CFL	40%	Lighting Residential CFL Med Natural light	10
Lights - Halogen	10%	Lighting Res 12V Halogen Med Natural	
Ceiling fans	4 standard ceiling fans	HVAC Residential Ceiling Fans	4
Air Conditioner		HVAC - Air Source Heat Pump (single split, high efficiency: COP/EER 4.4)	1
Main Toilet	Residential Toilet, Industry Standard Bathroom Services	Toilet	1

	Pipework		
HWS	Solar w electric boost 240L	HWS- Solar Thermal + Electric Boost	1
Electrical Connection		Site Power and Electrical Connection - Residential	
Water Connection		Plumbing, Water and Sewerage Connection, Residential	
As-built			
Water use	Average household water use	Average Water Use and Treatment, AUS, WA	
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em	
Refrigeration	Fridge/Freezer	Refrigeration, Residential Detailed (AUS) Op&Em	
Cooking	induction stove, electric oven	Cooking, Res Electric Oven Induction Stove Op&Em	
Actual Appliances			
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	
Stove	Electric Induction	Cooking, Residential Electric oven Induction Stove Op&Em	
Oven	Electric	Cooking, Residential Electric oven Induction Stove Op&Em	
Fridge	Vestfrost	Refrigeration, Residential Detailed (AUS) Em Refrigeration Vestfrost 387kWh/y	
Washing Machine	Samsung	Clothes Washer Embodied Appliances/ Laundry Appliances Samsung WFO754W7V	
Dishwasher	Asko	Dishwasher embodied Appliances/ Dishwashers Asko 154kWh/y	
Water usage (1000L/day)	Average Water Use & Treatment WA/AUS (no pool)	Average Water Use & Treatment WA/AUS (no pool)	

Table 11 House E, assume 6 star equivalent NatHERS thermal rating 39 MJ/m^2

	m^2	**Comments**		
Overall Area	462	Taken from google sketchup drawing (block Size)		
Internal Floor area	104	Taken from sketchup (different levels of ground floor)		
total internal including Garage		heating&cooling load		
unenclosed covered area	62.4			
Elevated Timber floor	78			
Concrete Pad ground	42	100mm slab on compacted fill		
Roof Area_new section&garage	74.6	tin area		
Roof Area_old section	95.2	old section of house		
Roof Area_verandah, red zincalume	9.16	old section of house		

Ceiling Area_old section	76.2	under roof		
Wall_ limestone (external)	201	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ Brick External	64	(external walls including double layer)		
Windows- Glazed Areas	9.78	Windows all single glazed (timber frame)		
Door- Glazed (swinging double doors)	9.6	2		
Doors	10	6		
Floor-Tiles	37.7	Bathroom/ kitchen/ Laundry		
Floor- Timber Floorboards	63.7	bedrooms, hallway & living room		
front veranda concrete	16.4			
concrete back pavers	46			
Brick Driveway	72.9			
Gravel	15	selection including all internal walls from sketchup		
Limestone garden retaining wall				
External Paint				
Lighting				
Mechanical Ventilation	0			
Thermal Demand	70MJ/m^2			
Lighting Run time	730hrs/y	1.4hrs per day		
Lux	150	min building code		
PV	1.5 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	3	Exhaust extraction fan, steel		
ceiling fan	5	Ceiling Fans Embodied		
HWS	1	Solar with gas booster		
RW tank	2500L	with pump		
Etool Material Inputs & assumptions				
Element	**Structure**	**eTool Assumption**	**Measurement**	**units**
Roof Area_new custom orb (10 degrees	Timber Truss ()	Roof - TimberTruss/SteelSheeting/5°Pitch/RakingCeiling	74.6	m^2 (pitch accounted for)
Roof Area_ old section 25deg	Timber Truss ()	Roof - TimberTruss/SteelSheeting/25°Pitch	76.4	
Roof Area_veranda, red	Timber Truss ()	Roof - TimberTruss/Steel/10°Pitch/noCeiling	9.16	
Wall_ Internal old section	300mm limestone	Limestone Wall, 250mm thick, with concrete mortar	201	
Wall_ Brick External	Brick 230mm	Double Brick Cavity Wall (90-50-90) render ext plaster int	64	m^2
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	42	m^2

Floor-Tiles	Tiles	Floor Covering - Tiles (Slate)	37.7	m^2
Floors- Old Section	concrete base	Concrete Floor, 100mm slab. 40MPa. 3.8% Reo - (old Section)	63.7	m^2
Floors- Timber Floorboards	25mm timber	Polished Timber floor - Glue Down	63.7	m^2
Floors- front veranda	concrete	Concrete Floor, 100mm slab. 40MPa. 3.8% Reo- front veranda	16.4	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	1.5 kW	
Doors- External	Timber	Door, Solid Core and Wooden Jam (Entry)	10	
Door- glass	glass sliding timber frame	Door, Solid timber frame glazing and Steel Jam (Entry)	9.6	6
Windows	timber frame sash windows	Windows, Residential Timber frame, Single Glaze, fly screen	9.78	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin	Standard Laundary sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower/ toilet	Standard Large Bathroom - WC/Bath-Shower/Basin*2/WallTiles	1	
Lighting- CFL	100% of the building	Lighting Residential LED High Natural Light	511	
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection, Residential		
gas connection		Gas Connection (single dwelling)		
HWS	HWS - solar w electric booster	HWS - Solar Thermal + Electric Boost (240L)	1	
Rainwater tank	2500L	2,500L Rainwater tank and Pump for Residence (Above Ground)	2500L	
outdoor Pavers	Concrete Pavers	Paving, concrete pavers (floors)	54	
Outdoor Driveway	Brick Driveway	Landscaping - Paving (brick)	73	
Garage Door	Steel	garage door by area	9.5	m^2
Garage Door	Steel	garage door by area	6.6	m^2
Limestone Garden Wall	limestone 250mm	Limestone Wall, 250mm thick,	11	m^2
Demolition		Standard residential demolition		
As-Built				
Water use		Average Water Use and Treatment, AUS, WA(no Pool)		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	**Assumptions**	
	Gas Stove	Cooking, Res Gas Stove Electric Oven Op&Em		
	Electric Oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		

Table 12: House F, assume 6 star equivalent NatHERS thermal rating 39 MJ/m^2

	m^2	Comments		
Overall Area	519	Taken from google sketchup drawing (block Size)		
Internal Floor area	165.9	Taken from sketchup (different levels of ground floor)		
total internal		heating&cooling load		
unenclosed covered area	38.9			
Concrete Pad ground	184.5	100mm slab on compacted fill		
Roof Area_new custom orb	137	tin area		
Roof Area_red zincalume	76.4	old section of house		
Roof Area_verandah, red zincalume	17.7	old section of house		
Ceiling Area	188	under roof		
Wall_ Internal timber stud	91.5	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ Internal brick	74			
Wall_ Brick External	84.3	(external walls including double layer)		
Wall_ Cladding External	107	with bulk insulation		
Windows- Glazed Areas	25	Windows and glass doors all single glazed (aluminium Frame)		
Door- Glazed	12.8	2		
Door External	3.4	2		
Door Internal	17.2	10		
Floor-Tiles	19.12	Bathroom/ toilet/ Laundry		
Floor- Timber Floorboards	146.8	stairs and front room		
timber front veranda	17.5			
timber back deck	21.4	not built yet		
Internal Paint		selection including all internal walls from sketchup		
External Paint				
Lighting				
Mechanical Ventilation	0			
Thermal Demand	39MJ/m^2			
Lighting Run time	730hrs/y	1.4hrs per day		
Lux	150	min building code		
PV	1.5 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	3	Exhaust extraction fan, steel		
ceiling fan	5	HVAC Residential Ceiling Fans		
HWS	1	Solar with gas booster		
RW tank	2500L	with pump		
Fireplace		HVAC Residential Wood Heater, Slow Combustion		
Etool Material Inputs &				

assumptions				
Element	**Structure**	**eTool Assumptions**	**Measurement**	**units**
Roof Area_new custom orb	Timber Truss	Roof - TimberTruss/SteelSheeting/5°Pitch/RakingCeiling	137	m^2 (pitch accounted for)
Roof Area_red zincalume 25deg	Timber Truss	Roof - TimberTruss/SteelSheeting/25°Pitch	76.4	
Roof Area_verandah, red zincalume	Timber Truss	Roof - TimberTruss/Steel/10°Pitch/noCeiling	17.7	
Ceiling	Plaster	Ceiling - Plasterboard+paint	188	m^2
Wall_ Cladding External	timber stud 140	140mm Timber stud Wall with FC Exterior, and PB and paint interior	107	
Wall_ Internal timber stud	timber stud 90	Timber Stud Internal Wall - Plasterboard/Paint both sides (Rockwool bulk ins)	91.5	
Wall_ Brick External	Brick 230mm	Double Brick Cavity Wall (90-50-90) render ext plaster int	84.3	m^2
Wall_ Internal brick	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior	74	m^2
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	184.5	m^2
Floor-Tiles	Tiles	Floor Covering - Tiles (ceramic/5mm)	19.12	m^2
Floors- Timber	Timber 25mm	Polished Timber floor - Glue Down	146.8	m^2
Floors- front deck	Timber decking	Floor, wooden decking, elevated on steel anchors	17.5	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	1.5 kW	
Doors- External	Timber	Door, Solid Core and Wooden Jam (Entry)	3.4	2
Doors- Internal	Timber	Door, Solid Core and Wooden Jam (Entry)	17.2	10
Door- sliding	glass sliding timber frame	Door, Residential Timber Alu Hybrid frame, Single Glaze, with hardware	12.8	2
Windows	timber frame	Windows, Residential Timber frame, Single Glaze, fly screen	25	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Ensuit	shower, toilet, vanity basin	Standard 1st Bathroom - WC/Shower-bath/Basin/WallTiles		
Main Bathroom	Bath/ Vanity/ shower/ toilet	Standard Large Bathroom - WC/Bath-Shower/Basin*2/WallTiles	1	
Lighting- LED	90% of building	Lighting Residential LED High Natural Light	511	
Lighting-Halogen	10% of building	Lighting Res 12V Halogen High Natural	511	
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection, Residential		
gas connection		Gas Connection (single dwelling)		
HWS	HWS - solar w electric booster	HWS - Solar Thermal + Gas Boost (240L) + Low Flow Showerheads	1	
Rainwater tank	2500L	Rainwater Tank (Polyethylene)	2500L	
electric pump for RW tank	Bianco Pumps	Electric Pump	0.8kW	
HVAC	split system air cond	HVAC - Air Source Heat Pump (single split, high efficiency: COP/EER 4.4)	hardly used	
As-Built				

Water use		Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**		
HVAC Residential Wood Heater, Open Fireplace	Wood			
	Gas Stove	Cooking, Res Gas Stove Electric Oven Op&Em		
	Electric Oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		

Table 13: House G, assume 7 star NatHERS thermal rating 29MJ/m^2

	m^2	**Comments**		
Overall Area	385.8	Taken from google sketchup drawing (block Size)		
Internal Floor area_ground floor	130.3	Taken from sketchup (different levels of ground floor)		
Internal Floor area_second floor	39.9			
total internal floor area	170.2	heating&cooling load		
Unenclosed covered area total	63			
Balcony	8.4			
Veranda	19			
Concrete Pad ground floor100 mm	152.4	100mm slab on compacted fill		
Concrete Pad ground floor 200mm	28			
second storey floor	48.3			
Roof Area_total	206.5	tin area		
Roof area_Horizontal	200			
Ceiling Area_ ground floor	175.36	under roof		
Ceiling Area_ second floor	57.8			
Wall_ Internal 50mm	69.6	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ Internal 90mm	64.3			
Wall_ double V	24.6			
Wall_ metal cladding_90mm (foil sissalation)	76.9	(external walls including double layer)		
Wall_ metal cladding_140mm	124.2	with bulk insulation		

Wall_rammed Earth	186			
Driveway section	82.9	concrete		
walkway section	24.6			
Glazing_Windows	16.64	Windows and glass doors all single glazed (aluminium Frame)		
Glazing_Sliding Doors	39			
Door_ internal	12.8	6		
Door_ External	11.5	1		
Door_ sliding	8.6	4		
Floor- Concrete	146.8	stairs and front room		
Back deck	44			
Washed Concrete	19			
Concrete Stairs		height = 2.7m		
Internal Paint		selection including all internal walls from sketchup		
External Paint				
Lighting		LED		
Mechanical Ventilation	0	N/A		
Thermal Demand	39MJ/m^2			
Lighting Run time	730hrs/y	1.4hrs per day		
Lux	150	min building code		
PV	2 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	3	Exhaust extraction fan, steel		
HWS	1	instant gas		
RW tank	3500L	with pump		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof Area_new custom orb	Timber Truss ()	Roof - TimberTruss/Steel/5°Pitch/noCeiling	200	m^2 (pitch accounted for)
Ceiling _Roof section	Plaster	Ceiling Lining - Plasterboard (12mm)	175.36	m^2
Insulation_roof	Rockwool R-2.5	Bulk Insulation - 100mm Rockwool (R2.8)	175.36	
Ceiling _under second story	Plaster	Ceiling Lining - Plasterboard (12mm)	57.8	
Wall_ Internal 50mm	50mm compressed fibre cement	CFC Panel cementitious core 50mm	69.6	
Wall_ Internal 90mm	timber stud 90 plasterboard	Timber Stud Internal Wall - Plasterboard/Paint both sides (Rockwool bulk ins)	64.3	
Wall_ double V	2x 50 mm compressed fibre cement	CFC Panel cementitious core 50mm x 2	24.6	

Wall_ metal cladding_90mm (foil sissalation)	skylight walls (plasterboard, bulk insulation, timber baton and metal sheeting+foil sissalation	90mm Timber stud Wall with 10mm PB interior, and metal cladding exterior	76.9	m^2
Wall_ metal cladding_140mm	90mm timber stud with bulk insulation, with metal cladding + 50 mm compressed fibre cement	140mm Timber stud Wall with 50mm FC interior, and metal cladding exterior	124.2	
Wall_rammed Earth		300mm Rammed Earth Wall (In situ Earth)	186	
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	152.4	m^2
Floor_ thickened concrete	225mm slab. 40MPa. 2% Reinforcement	Concrete Floor, 225mm slab. 40MPa. 2% Reinforcement	28	
Floor_ Second storey slab (fibre cement)	50mm compressed fibre cement for timber to glue to	Wall Lining - Compressed Fibre cement board (50mm)	48.3	
Floors- Timber	Timber 25mm upstairs	Polished Timber floor - Glue Down	57.8	m^2
Floors- Rubber	wet areas	Vinyl (PVC) "lino" Flooring	14.17	
Floors-deck	Timber decking back deck	Floor, wooden decking, elevated on steel anchors	44	m^2
Concrete walkway	washed concrete	Concrete Floor, 100mm slab. 25MPa. 3.8% Reo	24.6	
Concrete Driveway	washed concrete	Concrete Floor, 100mm slab. 25MPa. 3.8% Reo	82.9	
Concrete patio	washed concrete	Concrete Floor, 100mm slab. 25MPa. 3.8% Reo	19	
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	2 kW	
Doors- External	Timber	Door, Solid Core and Steel Jam (Entry)	1.9	1
Doors- Internal	Timber	Door, Hollow Core and Steel Jam	11	5
Door- sliding	door sliding	Door, commercial sliding with hardware	12.8	4
Glazing_sliding door	glass sliding timber frame	Door, commercial sliding glass with hardware	39	
Windows _windows	aluminium frame	Windows, Residential Aluminium Single Glaze, fly screen	16.64	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Ensuite	shower, toilet, vanity basin	Standard 1st Bathroom - WC/Shower-bath/Basin/WallTiles	1	
Main Bathroom	shower, toilet, vanity basin	Standard 1st Bathroom - WC/Shower-bath/Basin/WallTiles	1	
Lighting- LED	80% of building	Lighting Residential LED High Natural Light	511	
Lighting- Halogen	20% of building	Lighting Res 12V Halogen High Natural	511	
Staircase	timber staircase	Staircase, Timber	2.7m high	
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection,		

		Residential		
gas connection		Gas Connection (single dwelling)		
HWS	instant gas	HWS - Gas Instantaneous	1	
Rainwater tank&pump	3500L	3,500L Rainwater tank and Pump for Residence (Above Ground)	3500L	
Steel Gate		Painted Galvanised Steel Fence	2.68	
Fence		Painted Galvanised Steel Fence	7	
Gabion Wall		Gabion Wall (150x1000x500)-recycled rubble+concrete capping	2	
garage door		Garage Door (by area)	12.35	
HVAC	split system air cond	HVAC - Air Source Heat Pump (single split, high efficiency: COP/EER 4.4)	3	
As-Built				
Water use		Average Water Use & Treatment WA/AUS (no garden)		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	**Assumptions**	
	Gas Stove	Cooking, Res Gas Stove Electric Oven Op&Em		
	Electric Oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		

Table 14: House H, 8 star NatHERS thermal rating20 MJ/m^2

	m^2	**Comments**		
Overall Area	741	Taken from google sketchup drawing		
Internal Floor area_ ground	129.5	Taken from google sketchup drawing		
Internal Floor area_ floor 1	75	Taken from google sketchup drawing		
outdoor patio	30			
Total usable	234.5			
Concrete Pad area_	143	Taken from google sketchup drawing		

House				
Concrete Pad area_ Shed	60	Taken from google sketchup drawing		
Concrete_ Driveways	248	Taken from google sketchup drawing		
Back Patio_ Concrete	30	Taken from google sketchup drawing		
Roof Area_ custom Orb	148.5	102 curved + 46.5 flat sheets		
Roof Area_ Kliplok	77	Taken from sketchup		
Roof Area_ Back Patio	30	Taken from sketchup		
Ceiling_ floor 1 Area	96	Taken from sketchup		
Ceiling_ ground floor Area	144	Taken from sketchup		
Eaves	16.35	Taken from sketchup		
Wall_ Internal Area (90)	163	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ External Area (230)	186	(external walls including double layer)		
Wall_ External Area (140)	44			
Wall_ Rammed Earth	52.5			
Wall_ Shed	55			
Roof_ Shed	81.1			
Windows- Glazed Areas	40	Windows and glass doors all single glazed (aluminium Frame) with louvres		
Door- Glazed	18	living		
Door- shed	14.2	1x		
Glazing shed	3.5	2x		
Door Internal	18	6x top, 6x bottom		
Door external	4	2x		
Floor- Total	204.5	from plans		
Floor- Concrete	124.5	Laundry, Bathrooms and toilets		
Floor- Carpet	80	Bedrooms, 54 upper, 26 lower		
Internal Paint	390	selection including all internal walls from sketchup		
External Paint	126			
Lighting	18x 9W LED Globes	LED lighting		
Mechanical Ventilation	0			

Lighting Run time	730hrs/y	2hrs per day		
Lux	150	min building code		
PV	2 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	5	Exhaust extraction fan, steel		
Rainwater Tank	6000L	+ Pump, UV filter,		
Novagrey wastewater system	1	Grey Water System (plastic)		
tanks	2	Rainwater Tank in ground - Concrete		
Ceiling Fans	8	HVAC Residential Ceiling Fans		
Open Fireplace	1	HVAC Residential Wood Heater, Open Fireplace		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof_ Kliplock	kliplock 1 degree pitch Timber Truss	Roof - TimberTruss/SteelSheeting/5°Pitch/RakingCeiling	77	m^2 (pitch accounted for)
Curved custom orb Section	Roof	Roof - TimberTruss/SteelSheeting/10°Pitch/RakingCeiling/Insulation	47	m^2
Curved custom orb Section (inner)	Timber Frame Wall	Custom Orb interior Wall	28	m^2
Curved custom orb Section (outer)	Steel Frame Wall	Custom orb Exterior Steel wall with insulation	54	m^2
flat Custom Orb Section	Timber truss	Roof - TimberTruss/SteelSheeting/10°Pitch/RakingCeiling/Insulation	46.5	m^2
front wall	Timber Stud (600mm centres) 140mm	140mm Timber stud Wall with FC Exterior, and PB and paint interior	13.5	m^2
External Walls	230 cavity rendered brickwork (double brick)	Double Brick Cavity Wall (90-50-90) render ext plaster int	186	m^2
Rammed Earth	Rammed Earth 300mm	300mm Rammed Earth Wall (In situ Earth)	52.5	m^2
Internal Walls_Brick area	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior with 2x plaster	163	m^2
Internal Walls_Plaster	"	"	326	m^2
Interior wall-Paint (Excl ext	Paint 3 coats	Internal Finish - Paint Standard	326	m^2

wall				
Floor-Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	143	m^2
Floor-Upstairs	concrete	Floor, 170mm elevated slab, insul, steel sheeting formwork	75	m^2
Floors-Laundry, Bathrooms and toilets	polished Concrete	coloured Epoxy Concrete floor Coating	124.5	m^2
Floors-Bedrooms, Office & Theatre	Carpet over Concrete Slab	Floor Covering - Carpet (glue down/Nylon)	80	m^2
Floors-Concrete exposed aggregate driveway	Concrete-Painted	Concrete Floor, 100mm slab. 40MPa. 3.8% Reo	248	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	2 kW	
Doors-Internal	timber- hollow	Door, Hollow core and Steel Jam	18	6x top, 6x bottom
Doors-External	Timber	Door, Solid Core and Steel Jam (Entry)	4	2x
Door-Glazed	glass sliding	Door, commercial sliding glass with hardware	18	living
Windows	Aluminium Frame	Windows single glazed aluminium frame individual components	40	m^2
Louvres	aluminium	Louvre aluminium screen (by area)	9.5	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower, linen Cupboard	Bathroom - Shower/bath/ VB	1	
Ensuite	toilet/ Vanity/ shower	Standard 1st Bathroom - WC/shower/sink/wallTiles	1	
Powder room	toilet/ basin	PDR	2	
Lighting-Hardware	LED	Lighting Residential LED High Natural Light	1	building
Lighting-Operational energy	LED	Lighting Residential LED High Natural Light	1	
HWS	Solar w gas booster	HWS- Solar Thermal +gas boost (240L)+ Low Flow shower heads	1	
Rainwater tank	3000L tank	Rainwater tank Polyethylene	3000L	2x
Rainwater Pump	motor	Electric Pump	0.8 kWh	services Equipment
Stairs	Concrete	Staircase, Concrete (40Mpa, 2% reo)	2.5	m high
Stairs	Timber	Floor Covering - 25mm recycled timber (nail down)	6	m^2
Gas connection		Gas Connection (single dwelling)		

Water &sewer connection		Plumbing, Water and Sewerage Connection, Residential		
Electrical Connection		Site Power and Electrical Connection - Residential		
As Built				
Water use	Average household water use	Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeratio n	Fridge/Freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking	gas stove, electric oven	Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/G as**	**Etool Assumption (template)**		
	Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em		
	oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Clothes washer Em		
	Washing machine	Dishwasher Em		

Table 15 House L, 6 stars NatHERS thermal rating 39 MJ/m^2

	m^2	**Comments**		
Overall Area	345	Taken from google sketchup drawing		
Internal Floor area	263.5	Taken from sketchup (inc top floor)		
usable Floor area	293.5			
required cooling	223.5	cooling load		
Base Concrete Pad area	147.5	Including garage		
Raised Concrete Pad	116	top floor		
Alfresco (brick Pavers)	30	Taken from sketchup		
Other Brick Paved Areas	36	Taken from sketchup		
Roof Area	196	tin area		
Horizontal Roof Area	160	Taken from sketchup		
Top Floor Ceiling Area	120	Taken from sketchup		
Ground Floor Ceiling Area	116	not including garage		
Patio	31			
Internal Wall Area	180	Calculated from sketch up model (internal walls not attached to outside)		
External Wall Area	158	(external walls including double layer)		

Windows- Glazed Areas	43.6	Windows and glass doors all single glazed (aluminium Frame)		
Door- Glazed Sliding	8.6	laundry, patio		
Door- Glazed swinging	1.75	1x		
Door- Garage	16	1x 5m2 + 1 x 11m2		
Door External	1.75	1x		
Door Aluminium	1.75			
Door Internal	25	15x		
Floor- Total	263.5	from plans		
Floor-Tiles	31.5	Laundry, Bathrooms and toilets		
Floor- Timber Floorboards	76	Living Room & Hallways		
Floor-Carpet	72	Bedrooms, Office & Theatre		
Floor- Paint	39.317	garage		
Stairs				
Internal Paint	390	selection including all internal walls from sketch up		
External Paint	126.01			
Lighting		from plans		
Mechanical Ventilation	0			
Thermal Demand	100MJ/m^2			
Lighting Run time	730hrs/y	2hrs per day		
Lux	150	min building code		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	5	Exhaust extraction fan, plastic		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof	Timber Truss (25° pitch)	Roof - TimberTruss/SteelSheeting/25°Pitch	160	m^2 (pitch accounted for)
Ceiling under roofing	Plaster	Roof - TimberTruss/SteelSheeting/25°Pitch	160	m^2
Ceiling on ground floor	Plaster	Ceiling Lining - Plasterboard (12mm)	116	
External Walls	230 cavity rendered brickwork (double brick)	Double Brick Cavity Wall (90-50-90) render ext plaster int	158	m^2
Internal Walls_Brick area	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior	180	m^2
exterior Walls 190	"	masonry Wall	23	m^2
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	147.5	m^2

Ground Floor				
Floor- Concrete Pad first floor	250mm elevated slab. 40MPa. 4% Reo	Concrete Floor, 250mm elevated slab. 40MPa. 4% Reo	116	m^2
Floors- Laundry, Bathrooms and toilets	Tiles over Concrete Slab	Floor Covering - Tiles (ceramic/5mm)	31.5	m^2
Floors- Living Room & Hallways	Timber over Concrete Slab	Polished Timber Floor, Glue Down, Acoustic Ins	76	m^2
Floors- Bedrooms, Office & Theatre	Carpet over Concrete Slab	Floor Covering - Carpet (glue down/Nylon)	72	m^2
Floors- Garage	Concrete-Painted	coloured Epoxy Concrete floor Coating	39.317	m^2
Floors- alfresco	concrete Paving	Paving, 50mm brick	30	m^2
Paving_outdoor	50mm brick	Paving, 50mm brick	36	m^2
Patio	steel roof, timber supports	Pergola (timber) - covered	31	m^2
Doors- Internal	timber- hollow	Door, Hollow core and Steel Jam	25	15x
Doors- External	Timber	Door, Solid Core and Steel Jam (Entry)	1.75	1
Door- Glazed Sliding	glass sliding	Door, commercial sliding glass with hardware	8.6	2x laundry, patio
Door- Glazed swinging	1.75	Door, Solid Core and Steel Jam (Entry)	1.75	front door
Door- Garage (patio)		Garage Door (by area)	5	
Door- Garage	Steel	Garage Door (by Area)	11	
Door _ Glass Aluminium	1.75		1.75	
Windows	Aluminium Frame	Windows single glazed aluminium frame individual components	43.6	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1	
WC	toilet + pipework	WC	1	
Ensuite	Vanity/ shower/ WC	Standard 1st Bathroom - WC/shower/sink/wallTiles	1	
Powder room	toilet/ basin	PDR	1	
Lighting- Halogen	12 V 40W halogen downlights	Lighting Res 12V Halogen High Natural Light	1/2 Building	
Lighting- CFL	LED	Lighting Residential CFL High Natural Light	1/2 building	
HWS	Solar w electric Booster	HWS - Solar Thermal + Electric Boost (240L with Internal Switch)	1	
HVAC Evaporative Air Conditioner		HVAC Residential Evaporative Cooler	1	
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection, Residential		

Gas Connection		Gas Connection (single dwelling)		
gas heater		HVAC Residential Gas Heater, Flue, High Efficiency (75%)		
As-built				
Water use	Average household water use	Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/Freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking	induction stove, electric oven	Cooking, Res Electric Oven Induction Stove Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**		
Air Conditioner				
	Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em		
	Electric Oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		
	Dryer	Clothes Dryer Em		
	Entertainment/TV/Misc			

Table 16: House M: Assume 6 Star Equivalence NatHERS thermal rating 39MJ/m^2

	m^2	**Comments**	
Overall Area	345	Taken from Plans	
Usable Internal Floor area	166.8	Taken from Plans	
unenclosed covered area	9.5		
total usable floor area	176.3		
Concrete Pad area	184.6	Including garage	
Alfresco	9.46	Taken from Plans	
Roof Area	233.18	Taken from Plans	
Ceiling Area	211.81	Taken from Plans	
Internal Wall Area	130.23	Calculated from sketchup model (internal walls not attached to outside)	
External Wall Area	134.73	(external walls including double layer)	
Windows- Glazed Areas	36.9	Windows and glass doors all single glazed (aluminium Frame)	
Door- Glazed	3.51	2x	

Door- Garage	10.74	1x	
Door External	6.05	3x	
Door Internal	30	14x	
Floor- Total	166.8	from plans	
Floor-Tiles	19.88	Laundry, Bathrooms and toilets	
Floor- Timber Floorboards	50	Living Room & Hallways	
Floor-Carpet	62	Bedrooms, Office & Theatre	
Floor- Paint	36.5	garage	
Internal Paint	360.5	selection including all internal walls from sketchup	
External Paint	134.73		
Lighting	130	from plans	
Mechanical Ventilation	0		
Thermal Demand	39 MJ/m^2	star band rating	
Lighting Run time	730hrs/y	2hrs per day	
Lux	150	min building code	
PV	2.5 kW	used template (Solar PV System - zone 3 (Perth)	
Etool Material Inputs & assumptions			
Element	**Structure**	**Etool Assumption (template)**	**Measurement**
Roof	Timber Truss (25° pitch)	Roof - TimberTruss/SteelSheeting/25°Pitch	211.81m^2 (pitch accounted for)
Ceiling	Plaster	Roof - TimberTruss/SteelSheeting/25°Pitch	211.81m^2
External Walls	230 cavity rendered brickwork (double brick)	Double Brick Cavity Wall (90-50-90) render ext plaster int	134.73 m^2
Internal Walls	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior / Edited No Paint included	128 m^2 Brick Area 256 m^2 plaster &paint Area
Interior wall-Paint	Paint 3 coats	Internal Finish - Paint Standard	256.46 m^2
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	184.6 m^2
Floors- Laundry, Bathrooms and toilets	Tiles over Concrete Slab	Floor Covering - Tiles (ceramic/5mm)	19.88 m^2
Floors- Living Room & Hallways	Timber over Concrete Slab	Polished Timber Floor, Glue Down, Acoustic Ins	53 m^2
Floors- Bedrooms, Office & Theatre	Carpet over Concrete Slab	Floor Covering - Carpet (glue down/Nylon)	53 m^2
Floors- Garage	Concrete-Painted	coloured Epoxy Concrete floor Coating	53 m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	2.5kW
Doors- Internal	timber- hollow	Door, Hollow core and Steel Jam	30 m^2
Door- Garage	Steal	Garage Door (by Area)	10.74 m^2
Doors- External	Timber	Door, Solid Core and Steel Jam (Entry)	6 m^2
Door- Patio	Wood/glass	Door, Solid Timber Frame + Glazing and Steel	3.51 m^2

Windows	Aluminium Frame	Windows single glazed aluminium frame individual components	36.9 m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1
Main Bathroom	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1
WC	toilet + pipework	WC	1
Ensuite	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1
PDR	toilet/ basin	PDR	1
HWS	Solar w gas booster	HWS- Solar Thermal +gas boost (240L)+ Low Flow shower heads	
Rainwater tank	Steel Corrugated 3700L tank	Rainwater tank Polyethylene	3700L
Air Conditioner	Ducted Reverse Cycle	Ducting , flexible Aluminium, 250mm OD for HVAC	
Electrical Connection		Site Power and Electrical Connection - Residential	
Water Connection		Plumbing, Water and Sewerage Connection, Residential	
Gas Connection		Gas Connection (single dwelling)	
Lighting	Halogen 90%	Lighting Res 12V Halogen High Natural	
Lighting	CFL 10%	Lighting Residential CFL High Natural Light	
As Built			
Water use		Average Water Use and Treatment, AUS, WA	
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em	
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em	
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em	
Actual appliances			
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	
	R/hood	Exhaust Extraction Fan, Steel	
	Gas Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em	
	Electric oven	Cooking, Res Gas Stove Electric Oven Op&Em	
	Fridge	Refrigeration, Residential Detailed (AUS) Em	
	Washing Machine	Clothes washer Em	
	Dishwasher	Dishwasher Em	
	Average high efficiency tv and computer Appliances	Appliances, High Efficiency (AUS) - Op&Em	

Table 17: House O, 6 stars NatHERS thermal rating 39 MJ/m^2

	m^2	**Comments**		
Overall Area	345	Taken from google sketchup drawing		
Internal Floor	188	Taken from sketchup		

area				
Concrete Pad area	221	Including garage		
Alfresco (timber floor)	17.12	Taken from Plans		
Roof Area	264	tin area		
Ceiling Area	190	Taken from sketchup		
Eaves	16.35	Taken from sketchup		
Internal Wall Area	154	Calculated from sketchup model (internal walls not attached to outside)		
External Wall Area	126.01	(external walls including double layer)		
Windows-Glazed Areas	23.53	Windows and glass doors all single glazed (aluminium Frame)		
Door- Glazed	17.24	m^2 sliding, alfresco x 2, bedroom, study and laundry (5 total)		
Door- Garage	11.14	1x		
Door External	3.507	2x		
Door Internal	14.2	9x		
Floor- Total	131	from plans		
Floor-Tiles	17.82	Laundry, Bathrooms and toilets		
Floor- Timber Floorboards	67.8	Living Room & Hallways		
Floor-Carpet	48.74	Bedrooms, Office & Theatre		
Floor- Paint	39.317	garage		
timber front deck	10			
Internal Paint	390	selection including all internal walls from sketchup		
External Paint	126.01			
Lighting				
Mechanical Ventilation	0			
Thermal Demand	39MJ/m^2			
Lighting Run time	730hrs/y	2hrs per day		
Lux	150	min building code		
PV	1.5 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	4	Exhaust extraction fan, steel		
Swimming Pool	8.68	m^3 + Pump		
Rainwater Tank		+ Pump		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof	Timber Truss (25° pitch)	Roof - TimberTruss/SteelSheeting/25°Pitch	221	m^2 (pitch accounted for)
Ceiling	Plaster	Roof - TimberTruss/SteelSheeting/25°Pitc	190	m^2

		h		
External Walls	230 cavity rendered brickwork (double brick)	Double Brick Cavity Wall (90-50-90) render ext plaster int	126.01	m^2
Internal Walls_Brick area	90 brickwork (single Brick)	Single Brick Wall (90mm) - plaster & paint interior / Edited No Paint included	154	m^2
Internal Walls_Plaster	"	"	308	m^2
Interior wall- Paint (Excl ext wall	Paint 3 coats	Internal Finish - Paint Standard	308	m^2
Floor- Concrete Pad	100mm slab, 40MPa. 3.8%reo	Concrete Floor, 100mm slab, 40MPa. 3.8%reo	221	m^2
Floors- Laundry, Bathrooms and toilets	Tiles over Concrete Slab	Floor Covering - Tiles (ceramic/5mm)	17.82	m^2
Floors- Living Room & Halways	Timber over Concrete Slab	Polished Timber Floor, Glue Down, Acoustic Ins	67.8	m^2
Floors- Bedrooms, Office & Theatre	Carpet over Concrete Slab	Floor Covering - Carpet (glue down/Nylon)	48.74	m^2
Floors- Garage	Concrete-Painted	coloured Epoxy Concrete floor Coating	39.317	m^2
Floors- alfresco	Timber decking	External Timber deck (alfresco)	17.12	m^2
Floors- front deck	Timber decking	External Timber deck (alfresco)	10	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	1.5 kW	
Doors- Internal	timber- hollow	Door, Hollow core and Steel Jam	14.2	9x
Door- Garage	Steal	Garage Door (by Area)	11.14	1x
Doors- External	Timber	Door, Solid Core and Steel Jam (Entry)	3.507	2x
Door- Glazed	glass sliding	Door, commercial sliding glass with hardware	17.24	m^2 sliding, alfresco x 2, bedroom, study and laundry (5 total)
Windows	Aluminium Frame	Windows single glazed aluminium frame individual components	23.53	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1	
WC	toilet + pipework	WC	1	
Ensuite	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1	
Powder room	toilet/ basin	PDR	1	
Lighting- Hardware	LED	Lighting Residential LED High Natural Light	1	building
Lighting- Operational energy	LED	LED 720hrs /year consumption	426MJ/y	18 x 9W globes x 720 hrs/y
HWS	Solar w gas booster	HWS- Solar Thermal +gas boost (240L)+ Low Flow shower heads	1	

Rainwater tank	Steel Corrugated 2300L tank	Rainwater tank Polyethylene	2300L	
Rainwater Pump	motor	Electric Pump	0.8 kWh	services Equipment
Pool	fibreglass	fibreglass small Pool	8.68	no heating operational energy cost Per cubic metre
As Built				
Water use	Average household water use	Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/Freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking	gas stove, electric oven	Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	**Assumptions**	
Air Conditioner	Daikin Ducted Reverse Cycle	Ducting , flexible Aluminium, 250mm OD for HVAC HVAC Air Source Heat Pump (MEPs Average)		
	Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em		
	oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em		
	Dishwasher	Dishwasher Em		
	Washing machine	Clothes washer Em		

Table 18: House P, assume 6 star equivalent NatHERS thermal rating 39 MJ/m^2

	m^2	**Comments**		
Overall Area	350	Taken from google sketchup drawing		
Internal Floor area	161	Taken from sketchup		
Concrete Pad area	66.5	100mm slab on compacted fill		
Raised timber floor	103			
back deck (timber floor)	23.4			
Roof Area	222.5	tin area		
Ceiling Area	167.5	Taken from sketchup		
Eaves	29	ply board Not actually there*		
Wall_ Internal area (old)	78.5	Calculated from sketchup model (internal walls not attached to outside)		
Wall_ Internal new (new)	30			
Wall_ External Area (old)	75	(external walls including double layer)		

Wall_ External Area (new)	30			
Masonry Wall (100mm)	61	outside toilet and parapet wall		
Windows- Glazed Areas	27.5	Windows and glass doors all single glazed (aluminium Frame)		
Door- Glazed	19			
Door External	1.73	1		
Door Internal	13.7	8		
Floor- Total	131	from plans		
Floor-Tiles	12	Bathroom/ toilet		
Floor- Timber Floorboards	75	Living Room & Hallways		
timber front deck	8.5			
Louvre	2			
Internal Paint	390	selection including all internal walls from sketch up		
External Paint	126.01			
Lighting		from plans		
Mechanical Ventilation	0			
Thermal Demand	70MJ/m^2			
Lighting Run time	730hrs/y	2hrs per day		
Lux	150	min building code		
PV	4 kW	used template (Solar PV System - zone 3 (Perth)		
Smoke Detector	2	fire service smoke detector		
Exhaust Fan	2	Exhaust extraction fan, steel		
ceiling fan	1	HVAC Residential Ceiling fans		
Floor Heater	1	HVAC Residential Ground Source Heat Pump		
Etool Material Inputs & assumptions				
Element	**Structure**	**Etool Assumption (template)**	**Measurement**	**units**
Roof	Timber Truss ()	Roof - TimberTruss/SteelSheeting/15°Pitch	222.5	m^2 (pitch accounted for)
Ceiling	Plaster	Roof - TimberTruss/SteelSheeting/15°Pitch	167.5	m^2
External Walls Old	timber stud (400)	Timber Stud Ext Wall - FC/WB Clad & PB Lining+Insul	75	m^2
External Walls new	Steel Stud (600mm centres)	Timber stud (600mm centre)-steel clad+pb+finish	30	m^2
External walls Single Brick	90 brickwork (single Brick)	Masonry Wall - Single Brick (90mm)	61	m^2
Internal Walls_new	Steel Stud (600mm centres)	Steel stud, 600mm centre, plbrd pt both sides insul	30	m^2
Internal Walls_old	timber stud (400)	Timber Stud Internal Wall - Plasterboard/Paint both sides (Rockwool bulk ins)	75	
Interior wall-Paint (Excl ext wall			30	m^2
Floor- Concrete Pad	100mm slab, 40MPa.	Concrete Floor, 100mm slab,	66.5	m^2

(living Room)	3.8%reo	40MPa. 3.8%reo		
Floors- Hallways, Bedroom &bathroom	Timber raised	Floor, elevated timber frame, nail down timber flooring	103	m^2
Floors- back deck	Timber decking	Deck, Elevated Timber on Steel Anchor	23.4	m^2
Floors- front	Timber decking	Deck, Elevated Timber on Steel Anchor	8.5	m^2
PV	Panel/ inverter/ installation	Solar PV System - Zone 3 (Perth)	4 kW	
Doors- External	Timber	Door, Solid Core and Steel Jam (Entry)	1.73	8
Door- double Glazed	glass sliding timber frame	Door, Residential Timber Alu Hybrid frame, Double Glaze,	19	3
Windows	Aluminium Frame	Windows, Residential Timber Alu Hybrid frame, Single Glaze, fly screen	27.5	m^2
Louvres	Aluminium Frame	Louvre aluminium screen (by area)	2	m^2
Kitchen cabinet	laminated board for cupboards, shelves, drawers	kitchen cabinetry Medium	1	
Laundry	Steel basin/ linen cupboard	Standard Laundry sink (Steel) + Services	1	
Main Bathroom	Bath/ Vanity/ shower	Bathroom - Shower/bath/ VB	1	
WC	toilet + pipework	WC	1	
Outdoor Powder room	toilet/ basin	PDR	1	
Lighting Residential LED High Natural Light	LED	Lighting Residential LED High Natural Light	1	building
Electrical Connection		Site Power and Electrical Connection - Residential		
Water Connection		Plumbing, Water and Sewerage Connection, Residential		
gas connection		Gas Connection (single dwelling)		
HWS	HWS - Gas Instantaneous	HWS - Gas Instantaneous	1	
As-built				
Water use		Average Water Use and Treatment, AUS, WA		
Appliances	Entertainment, Laundry, Dishwasher	Appliances, Residential Average (AUS) Op&Em		
Refrigeration	Fridge/ freezer	Refrigeration, Residential Detailed (AUS) Op&Em		
Cooking		Cooking, Res Gas Stove Electric Oven Op&Em		
Additional appliances	**Energy/Water/Gas**	**Etool Assumption (template)**	**Assumptions**	
Air Conditioner	Daikin split system	HVAC Air Source Heat Pump Embodied (single-split)		
	Hotplate	Cooking, Res Gas Stove Electric Oven Op&Em		
	oven	Cooking, Res Gas Stove Electric Oven Op&Em		
	Fridge	Refrigeration, Residential Detailed (AUS) Em	op = 454kWh/y	
	Dishwasher	Dishwasher Em	runs an average	

			of once per day	
	Washing machine	Clothes washer Em	runs an average of once per day	
	Heat Lamp	lighting Lizard Heat Lamp		

Appendix C: Audit Interviews (summer)

House	C	E	F	G	H
Who Lives in this House?	Two Adults, Two Children, one Child and dad away from home during week, one child and Mum at home during week	Two Adults, Working so only home on weekends and night time	4 people, Mum, Dad, young Kids at school, home weekends and night time, Dad home 2 weekdays	two adults, 1 older son, working most of the time, home on weekends	4 people, Dad working away, Mum working from home (young family) so Kids at School
Why did you decide to participate in this project?	Wanted monitoring equipment so signed up for project	Advertisement seen in the Herald and see themselves a sustainably conscious people	Interested in sustainability to reduce energy usage and impacts. Try contribute to the sustainability message	interested in the performance of their 7 star house	House Achieved HIA Green smart award so wanted to see how it performs
How important is it for you to reduce your greenhouse gas emissions?	important to have low GHG emissions	Very important, do travel a bit (flying)	Very important, Climate change on agriculture in particular	don't see it as important because don't believe the effect is as bad as industry	Very Important for next generation
How important is it for you to reduce your energy consumption?	Subset for GHG reduction being more important	Important, as long as it doesn't interfere with lifestyle too much. Think already conscious about it	Pretty important, save money contribute to making efficiency a normal way of living	not so much, don't believe the energy usage is large,	Reduce Energy = reduce GHG
How important is it for you to reduce your water consumption?	very important, been trying to establish plants	little bit less important as they enjoy their nice garden	Very important	important, chose house due to low water garden	Very, spent time focussing on this area during build, greywater production isn't enough to irrigate garden
How important is it for you to live in a comfortable home?	very important which is why doing renovations to improve liveability	Very	Not a priority	very important, solar passive design is great	Very, spend a lot of time in the home, wanted a pleasant life with young children

How do you think people view reducing their greenhouse gas emissions?	people are unaware of the GHG concept and how bad GHG is which makes them comfortable	In Freo is good, support is growing in broader community as financial benefits become greater	People worry about it but do not understand properly, if they do understand they don't want to make major changes	people are confused as the message isn't effective, friends aren't as green	They don't have the same view as us, they think it is too hard, expensive
Is that how it is in your local community	Hilton/ Freo are more engaged and friends and community are more involved		Freo are probable a bit more aware	Freo groups are more conscious	Freo have a reputation to be forward thinking about sustainability
Do you think more people think it is important to reduce their greenhouse gas emissions now compared to one year ago?		Yes steadily growing, growing utility prices, Sustainability summit in Paris			-
Is there support to reduce greenhouse gas emissions in your community?	Freo used to do this with smaller housing programs	Not aware of any	No support	yes if you seek out support (explanation of bills)	Freo Program with goal setting with 6 month re-evaluation
Is there support to reduce your greenhouse Gas emissions in your household?	Yes all are on the same page except for water usage	energy usage support	yes, talk about saving resources	financial support incentives as long as no impact on lifestyle	Explaining to kids the importance to save energy and water
Have you tried reducing your greenhouse gas emissions in the past?	Yes, Pre kids were much more proactive	No, do have solar panels, water efficient gardens and rainwater tank	always have tried to keep consumption as low as possible	yes, conscious of savings worthwhile, halogen globes to LED	Yes, making sure the home is retrofitted with new technologies to assist

Did you encounter any barriers with this?	Kids and the life stage that they are at	none	climate being hot, inefficient reticulation, stopped self-monitoring energy use because of the data equipment	Cannot do things that are inconvenient	That houses aren't built to consider future greywater, Blackwater separation options which makes retrofits in the future very difficult
What facilitated making changes?	interested and passionate as well as doing the living smart course	City of Fremantle, self-awareness			Increasing awareness from the community

House	**L**	**M**	**O**	**P**
Who Lives in this House?	Two elderly adults home most days and granddaughter working 38 hour week, visitors most weekends	mum and 3 boys, 2 boys home lots, other boy at school and mum working	Two Adults working full time	5 ppl, two adults and 3 young children, Dad work all week, Mum home with kids all day, craft business from home
Why did you decide to participate in this project?	sustainability idea, save money, do their bit for the planet	great idea, helping the environment would be a bonus, find out the high use sources	Building a remediation, to find out how home works and to try and be as sustainable as possible	Like the idea as outdoor people from working class background
How important is it for you to reduce your greenhouse gas emissions?	moderately, a good lifestyle is the most important	really important, small scale reductions lead to larger scale	Extremely important (global Warming	Pretty important (not top of list)
How important is it for you to reduce your energy consumption?	quite important as it leads to saving money	very	Extremely as there are only two people, trying to save money, improve lifestyle	Important from cost perspective + environment
How important is it for you to reduce your water consumption?	quite important, already try to implement	very, garden, toilets and laundry use rainwater	Important to understand how to manage gardens, rainwater tank was mandatory should be for everyone, having a pool means that saving	not as focussed on water

			water is even more important	
How important is it for you to live in a comfortable home?	very important	important for the whole family	Extremely important as work hard, want to live comfortably	Very, Cost efficiency is more important, enjoy being home
How do you think people view reducing their greenhouse gas emissions?	people want to be involved however adolescent friends don't really care	People don't know enough or unaware of the effect the changes they make	spoken about a lot, naturally ignore and take for granted the cost of electricity and water	Everyone wants to try and do their thing, choosing to change isn't as likely
Is that how it is in your local community			Vancouver had a different mindset than Perth	
Do you think more people think it is important to reduce their greenhouse gas emissions now compared to one year ago?			Grown a bit, but not really quickly	Yes, could be due to media awareness
Is there support to reduce greenhouse gas emissions in your community?	Freo Council subsidies for verge and mulch, compost bins and planting trees	not aware if anything besides their house being mandatory to have rainwater tanks and PV due to being a high density infill house	Unaware of any	sustainability workshops, open houses(Josh's House)
Is there support to reduce your greenhouse Gas emissions in your household?	talk about it and try to support each other, encourage correct behaviours	on the way, hard to convince kids, media is helping inform them	Yes, try to act sustainably and encourage to utilise solar power	Yes, saving money is high priority
Have you tried reducing your greenhouse gas emissions in the past?	Yes, Replacing inefficient lighting, turning lights off, switching off PowerPoints at walls	yes, continually trying, turning lights off, heat purging in early morning, shutting house during day	Dishwasher, power points off at wall	yes,
Did you encounter any barriers with this?	no, do it as part of the lifestyle	behavioural changes, turning lights out	old habits and remembering	House inefficiencies, baths, water pressure, no insulation, messing around with floor

				heater
What facilitated making changes?	nothing		building the new house, replacement costs vs cost of new appliances	

Appendix D: Audit interviews (winter)

House	C	E	F	G
Has there been any changes to your routine	things that don't cost lots of money	No	turning off power at wall, block vents	not really
Are you finding anything particularly difficult	bath time reductions	N/A	nothing	N/A
Has anything helped in making these changes	seeing data and being made aware through audits	N/A	knowing the power usage of appliances	N/A
Are the rest of the family participating?	yes	they are aligned	not really, keep on reminding them	not really
How often are you logging into the website	a few time, takes a long time to log on	once after the first visit	N/A	not often
How useful are you finding the information on the monthly reports?	very	very useful	very	do look at it
Do you still think your view about energy and water conservation remains the same in six months?	reinforcing importance of efficiency	instead of choosing fruit trees natives are chosen for water wise gardens	yes	same
Are you more conscious of your energy and water usage on a daily basis?	yes	no	yes	not more, still been conscious

House	H	L	M	O	P
Has there been any changes to your routine	kids are getting older so they now have separate showers, universal switches purchased, extra rainwater tank being installed	replaced globes with efficient ones, daughter staying on weekends, so extra person in house, shade sail outside laundry	son moved out, reduced showers, younger son is buying into behaviour change, mulched garden, screens on front windows	changed timer on pool and try and utilise solar production	Shorter showers, trying to modify behaviour
Are you finding anything particularly difficult	No	no	continually educating kids	when visitors stay	keeping an eye on the kids use
Has anything helped in making these changes	data, breaking things down into things that can actually be done	tips from summer audit	reminders, hints, updates and the goals	audits, tips	being able to visibly see the usage through the data monitoring system
Are the rest of the family participating?	no, they are understanding the concept a little bit more	yes, interested in the project since last visit	one son is	yes, except when extended family come	they are aware but not fully involved
How often are you logging into the website	once a week	occasionally	not at all	not very often	only a few times
How useful are you finding the information on the monthly reports?	good	useful	great	very	very useful
Do you still think your view about energy and water conservation remains the same in six months?	still the same	more aware, thinking of installing rainwater tank or solar panels	strengthened	same	views haven't changed, more relaxed as the data was low compared to the average
Are you more conscious of your energy and water usage on a daily basis?	yes definitely	yes, subconsciously aware	yes, more conscious	probably slightly more conscious	Yes, think about it a lot more

Appendix E: Top 30 Materials By Total Impact

Table 19: House B Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	24,503
Steel | General | Unspecified | Industry Average	9,484
Concrete | Unreinforced | 40 MPa | Industry Average	9,258
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	6,960
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	5,937
Gases | Refrigerants | R134 | Industry Average	5,908
Aluminium | General | Industry Average	5,854
Windows | Aluminium Framed | No Thermal Break | Single Glaze | Domestic 50% Opening | Industry Average	5,187
Concrete | Unreinforced | Unspecified | Industry Average	3,587
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	2,399
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	2,345
Paints and Finishes | Unspecified | 1 Coat | Industry Average	2,163
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	2,063
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	1,948
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	1,940
Timber | Plywood | Unspecified | Industry Average	1,788
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	1,680
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	1,677
Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	1,546
Steel | Stainless | Unspecified | Industry Average	1,465
Resins and Adhesives | Epoxy Resin | Industry Average	1,292
Plastics | Polyurethane | Unspecified | Industry Average	1,205
Plastics | General | Unspecified | Industry Average	1,100
Glass | Flat Glass | Industry Average	876

Material	Total (kg CO2-eq)
Finished Products | Electrical Goods | Inverter | Industry Average	839
Carpets and Floor Coverings | Underlay | Nylon | Industry Average	805
Timber | Hardwood | Industry Average	796
Resins and Adhesives | Urea Formaldehyde | Industry Average	771
Ceramics | Ceramic Tiles | Industry Average	764
Plastics | Polypropylene | Injection Moulding | Industry Average	709

Table 20: House C Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Steel | General | Unspecified | Industry Average	8,913
Gases | Refrigerants | R134 | Industry Average	5,908
Aluminium | General | Industry Average	5,771
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	5,256
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	3,285
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	2,999
Gases | Refrigerants | R134 No manufacturing fugitive emissions | Industry Average (No fugitive emissions from production)	2,951
Roofing | Tiles | Clay and Terracotta | Unspecified | Industry Average	2,811
Fibre Board | Fibre Cement | Medium Density. 1250 kg/t | Industry Average	2,293
Glass | Flat Glass | Industry Average	2,256
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	1,654
Plastics | General | Unspecified | Industry Average	1,589
Steel | Stainless | Unspecified | Industry Average	1,517
Insulation | Blankets and Batts | Mineral Wool | Blanket | Unspecified | Industry Average	1,330
Paints and Finishes | Unspecified | 1 Coat | Industry Average	1,291
Concrete | Unreinforced | 30 MPa | Industry Average	1,181
Timber | Plywood | Unspecified | Industry Average	1,174
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	1,061
Finished Products | Electrical Goods | Inverter | Industry Average	1,044
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	852
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	668
Timber | Hardwood | Industry Average	641
Insulation | Blankets and Batts | Glass Fibre Batts | R 1.5 | Industry Average	501
Plastics | Polystyrene | Expanded Polystyrene | Industry Average	446
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	441
Timber | Glue Laminated | Unspecified | Industry Average	394

Material	Total (kg CO2-eq)
Metals (excluding steel and Aluminium) | Copper | Industry Average	339
Plastics | Polyurethane | Unspecified | Industry Average	332
Insulation | Rigid Foams and Boards | Polyurethane | Industry Average	326

Table 21: House E Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Rock and Stone | Stone - Limestone | Industry Average	18,773
Steel | General | Unspecified | Industry Average	8,834
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	8,230
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	7,652
Concrete | Unreinforced | 40 MPa | Industry Average	7,258
Gases | Refrigerants | R134 | Industry Average	5,908
Aluminium | General | Industry Average	4,568
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	3,359
Bulk Aggregates Sands and Soils | Sand (Compacted) | Unspecified | Industry Average	3,097
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	2,372
Concrete | Unreinforced | Unspecified | Industry Average	2,118
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	1,821
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	1,696
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	1,296
Finished Products | Electrical Goods | Inverter | Industry Average	1,168
Plastics | Polyurethane | Unspecified | Industry Average	1,076
Timber | Plywood | Unspecified | Industry Average	1,038
Plastics | General | Unspecified | Industry Average	972
Paints and Finishes | Unspecified | 1 Coat | Industry Average	965
Steel | Stainless | Unspecified | Industry Average	890
Timber | Hardwood | Industry Average	879
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Resins and Adhesives | Epoxy Resin | Industry Average	589
Windows | Timber Framed | Single Glaze | Domestic 50% Opening | Industry Average	517

Material	Total (kg CO2-eq)
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.56mm | Industry Average	483
Plastics | Polystyrene | Expanded Polystyrene | Industry Average	446
Glass | Flat Glass | Industry Average	416
Fibre Board | Fibre Cement | Medium Density. 1250 kg/t | Industry Average	407
Roofing | Tiles | Slate | Industry Average	396
Ceramics | Ceramic Tiles | Industry Average	377

Table 22: House F Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Concrete | Unreinforced | 40 MPa | Industry Average	10,967
Steel | General | Unspecified | Industry Average	10,095
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	8,798
Gases | Refrigerants | R134 | Industry Average	5,908
Aluminium | General | Industry Average	4,923
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	4,635
Rubber | Synthetic | Industry Average	3,866
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	3,294
Fibre Board | Fibre Cement | Compressed 1750kg/m3 | Industry Average	3,062
Gases | Refrigerants | R134 No manufacturing fugitive emissions | Industry Average (No fugitive emissions from production)	2,951
Plastics | Polyurethane | Unspecified | Industry Average	2,330
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	2,199
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	2,132
Timber | Plywood | Unspecified | Industry Average	1,682
Paints and Finishes | Unspecified | 1 Coat | Industry Average	1,617
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	1,474
Windows | Timber Framed | Single Glaze | Domestic 50% Opening | Industry Average	1,321
Concrete | Unreinforced | Unspecified | Industry Average	1,288
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	1,244
Timber | Hardwood | Industry Average	1,205
Steel | Stainless | Unspecified | Industry Average	1,135
Ceramics | Ceramic Tiles | Industry Average	1,122
Insulation | Blankets and Batts | Mineral Wool | Blanket | Unspecified | Industry Average	1,091
Plastics | General | Unspecified | Industry Average	888
Windows | Hybrid Framed | Single Glaze Ali and Timber | Domestic 50% Opening | Industry Average	842
Finished Products | Electrical Goods | Inverter | Industry Average	770
Plastics | Polypropylene | Injection Moulding | Industry Average	709

Material	Total (kg CO2-eq)
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	672
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	544
Resins and Adhesives | Epoxy Resin | Industry Average	476

Table 23 House G Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Gases | Refrigerants | R134 No manufacturing fugitive emissions | Industry Average (No fugitive emissions from production)	19,238
Steel | General | Unspecified | Industry Average	18,764
Concrete | Unreinforced | 40 MPa | Industry Average	13,910
Aluminium | General | Industry Average	13,215
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	11,459
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	10,718
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	8,404
Timber | Hardwood | Industry Average	7,325
Fibre Board | Fibre Cement | Medium Density. 1250 kg/t | Industry Average	7,087
Concrete | Unreinforced | 25 MPa | Industry Average	6,897
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	5,658
Gases | Refrigerants | R134 | Industry Average	5,161
Concrete | Light Weight | Autoclaved Aerated (density 700kg/m3) | Industry Average	4,473
Steel | Stainless | Unspecified | Industry Average	3,787
Timber | Softwood | Industry Average	3,754
Rubber | Synthetic | Industry Average	3,655
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	3,429
Timber | Plywood | Unspecified | Industry Average	3,305
Paints and Finishes | Unspecified | 1 Coat | Industry Average	3,038
Insulation | Blankets and Batts | Mineral Wool | Blanket | Unspecified | Industry Average	2,897
Finished Products | Electrical Goods | Inverter | Industry Average	2,824
Glass | Flat Glass | Industry Average	2,425
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	1,922

Material	Total (kg CO2-eq)
Plastics | Polyurethane | Unspecified | Industry Average	1,917
Timber | Glue Laminated | Unspecified | Industry Average	1,745
Insulation | Blankets and Batts | Polyester Batts | R 2.5 | Industry Average	1,501
Plastics | Polypropylene | Injection Moulding | Industry Average	1,404
Plastics | General | Unspecified | Industry Average	1,259
Plaster and Gypsum Derived Products | Plaster Board | 10mm Sheets | Industry Average	1,250
Insulation | Blankets and Batts | Glass Fibre Batts | Unspecified | Industry Average	1,171

Table 24: House H Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Concrete | Unreinforced | 40 MPa | Industry Average	24,356
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	19,508
Steel | General | Unspecified | Industry Average	17,052
Aluminium | General | Industry Average	9,811
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	6,455
Gases | Refrigerants | R134 | Industry Average	5,908
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	5,479
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	4,558
Concrete | Unreinforced | Unspecified | Industry Average	3,859
Timber | Plywood | Unspecified | Industry Average	3,482
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	2,933
Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	2,877
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	2,605
Glass | Flat Glass | Industry Average	2,564
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	1,922
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	1,907
Paints and Finishes | Unspecified | 1 Coat | Industry Average	1,849
Steel | Stainless | Unspecified | Industry Average	1,723
Finished Products | Electrical Goods | Inverter | Industry Average	1,579
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	1,571
Carpets and Floor Coverings | Underlay | Nylon | Industry Average	1,497
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.56mm | Industry Average	1,414
Plastics | General | Unspecified | Industry Average	1,396
Insulation | Blankets and Batts | Mineral Wool | Blanket | Unspecified | Industry Average	895

Material	Total (kg CO2-eq)
Timber | Hardwood | Industry Average	817
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Paints and Finishes | Wood Stains and Finishes | General | Industry Average	609
Metals (excluding steel and Aluminium) | Copper | Industry Average	552
Insulation | Blankets and Batts | Glass Fibre Batts | Unspecified | Industry Average	493
Ceramics | Porcelain Sanitary Products | Toilet | Industry Average	485

Table 25: House L Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Concrete | Unreinforced | 40 MPa | Industry Average	26,005
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	20,906
Steel | General | Unspecified | Industry Average	19,260
Gases | Refrigerants | R134 | Industry Average	5,908
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	4,956
Aluminium | General | Industry Average	4,254
Timber | Plywood | Unspecified | Industry Average	3,718
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	3,341
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	3,184
Concrete | Unreinforced | 25 MPa | Industry Average	2,757
Concrete | Unreinforced | Unspecified | Industry Average	2,635
Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	2,589
Glass | Flat Glass | Industry Average	2,506
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	2,109
Rubber | Synthetic | Industry Average	2,062
Plastics | General | Unspecified | Industry Average	1,695
Paints and Finishes | Unspecified | 1 Coat | Industry Average	1,649
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	1,441
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	1,433
Bulk Aggregates Sands and Soils | Sand (Compacted) | Unspecified | Industry Average	1,406
Plastics | Polyurethane | Unspecified | Industry Average	1,354
Carpets and Floor Coverings | Underlay | Nylon | Industry Average	1,347
Steel | Stainless | Unspecified | Industry Average	1,131
Bulk Aggregates Sands and Soils | Aggregate (Compacted) | Unspecified | Industry Average	1,061
Ceramics | Ceramic Tiles | Industry Average	1,033

Material	Total (kg CO2-eq)
Timber | Hardwood | Industry Average	978
Resins and Adhesives | Urea Formaldehyde | Industry Average	862
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	689
Resins and Adhesives | Epoxy Resin | Industry Average	582

Table 26: House M Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	14,450
Concrete | Unreinforced | 40 MPa | Industry Average	10,973
Steel | General | Unspecified | Industry Average	10,753
Gases | Refrigerants | R134 | Industry Average	5,908
Gases | Refrigerants | R134 No manufacturing fugitive emissions | Industry Average (No fugitive emissions from production)	5,903
Aluminium | General | Industry Average	5,509
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	5,318
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	3,501
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	3,359
Concrete | Unreinforced | Unspecified | Industry Average	3,173
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	2,345
Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	2,265
Finished Products | Electrical Goods | Inverter | Industry Average	1,839
Glass | Flat Glass | Industry Average	1,832
Resins and Adhesives | Epoxy Resin | Industry Average	1,625
Paints and Finishes | Unspecified | 1 Coat | Industry Average	1,588
Timber | Plywood | Unspecified | Industry Average	1,569
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	1,516
Finished Products | Electrical Goods | Light Fittings | 12V Transformers | Industry Average	1,450
Rubber | Synthetic | Industry Average	1,448
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	1,191
Carpets and Floor Coverings | Underlay | Nylon | Industry Average	1,179
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	1,094

Material	Total (kg CO2-eq)
Plastics | General | Unspecified | Industry Average	1,018
Plastics | Polyurethane | Unspecified | Industry Average	1,004
Timber | Hardwood | Industry Average	998
Steel | Stainless | Unspecified | Industry Average	944
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Insulation | Rigid Foams and Boards | Polyurethane | Industry Average	652
Metals (excluding steel and Aluminium) | Copper | Industry Average	576

Table 27: House O Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	14,760
Concrete | Unreinforced | 40 MPa | Industry Average	13,136
Steel | General | Unspecified | Industry Average	11,000
Gases | Refrigerants | R134 | Industry Average	5,908
Gases | Refrigerants | R134 No manufacturing fugitive emissions | Industry Average (No fugitive emissions from production)	5,903
Aluminium | General | Industry Average	5,251
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	3,598
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	3,576
Concrete | Unreinforced | Unspecified | Industry Average	3,300
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	2,447
Paints and Finishes | Unspecified | 1 Coat | Industry Average	2,294
Glass | Flat Glass | Industry Average	2,115
Rubber | Synthetic | Industry Average	1,908
Timber | Plywood | Unspecified | Industry Average	1,878
Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	1,828
Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	1,753
Resins and Adhesives | Epoxy Resin | Industry Average	1,637
Insulation | Blankets and Batts | Glass Fibre Batts | R 4.0 | Industry Average	1,582
Steel | Stainless | Unspecified | Industry Average	1,477
Timber | Hardwood | Industry Average	1,465
Finished Products | Electrical Goods | Inverter | Industry Average	1,250
Plastics | Polyurethane | Unspecified | Industry Average	1,244
Fibreglass | Unspecified | Industry Average	1,229

Material	Total (kg CO2-eq)
Plastics | General | Unspecified | Industry Average	1,202
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	1,190
Carpets and Floor Coverings | Underlay | Nylon | Industry Average	912
Plastics | Polypropylene | Injection Moulding | Industry Average	740
Metals (excluding steel and Aluminium) | Copper | Industry Average	529
Ceramics | Ceramic Tiles | Industry Average	478
Plastics | Polystyrene | Expanded Polystyrene | Industry Average	446

Table 28: House P Top 30 Materials By Total Impact

Material	Total (kg CO2-eq)
Finished Products | Electrical Goods | Solar PV Panels | Monocrystalline | Unspecified | Industry Average	6,997
Steel | General | Unspecified | Industry Average	6,076
Gases | Refrigerants | R134 | Industry Average	5,908
Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	4,158
Concrete | Unreinforced | 40 MPa | Industry Average	3,953
Aluminium | General | Industry Average	3,066
Concrete | Reinforced | 1.0% Reinforcement by mass | 30 MPa | Industry Average	2,610
Fibre Board | Fibre Cement | Medium Density. 1250 kg/t | Industry Average	2,524
Finished Products | Electrical Goods | Inverter | Industry Average	2,414
Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	2,218
X Non-Compliant Data | Timber | Particle Board | Unspecified | Industry Average	2,213
Windows | Hybrid Framed | Single Glaze Ali and Timber | Domestic 50% Opening | Industry Average	1,931
Windows | Hybrid Framed | Double Glaze Ali and Timber | Domestic 50% Opening | Industry Average	1,588
Timber | Plywood | Unspecified | Industry Average	1,256
Paints and Finishes | Unspecified | 1 Coat | Industry Average	913
Insulation | Blankets and Batts | Mineral Wool | Blanket | Unspecified | Industry Average	895
Steel | Stainless | Unspecified | Industry Average	831
Plastics | General | Unspecified | Industry Average	780
Plastics | Polypropylene | Injection Moulding | Industry Average	709
Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	610
Insulation | Blankets and Batts | Glass Fibre Batts | R 1.5 | Industry Average	589
Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	516

Material	Total (kg CO2-eq)
Plastics | Polystyrene | Expanded Polystyrene | Industry Average	446
Steel | Galvanised Structural | Industry Average	434
Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	388
Metals (excluding steel and Aluminium) | Copper | Industry Average	387
Timber | Glue Laminated | Unspecified | Industry Average	346
Timber | Hardwood | Industry Average	334
Plastics | Polyurethane | Unspecified | Industry Average	332
Ceramics | Porcelain Sanitary Products | Toilet | Industry Average	324

Appendix F: Energy, Water and Gas raw data for the eTool Predicted per Dwelling, Measured per Dwelling and measured per occupant data

2015 summary

eTool Predicted

Houses	Actual Occupant	eTool Average	Grid electricity peak (kWh)	Grid electricity (MJ)	Grid Electricity adjusted(kWh)	solar utilised + exported (	Solar production (MJ)	Gas (MJ)	Mains water (kL)	Wastewater	Rainwater (kL)
B	4	3.32	4197.8	15112	3507.8	2484	4968	4791	336	194	5
C	4	1.85	3872.2	13940	2837.2	3726	7452	0	243	106	0
E	2	1.85	3220.3	11593	2185.3	3726	7452	2272	226	106	5
F	4	3.32	4207.8	15148	3172.8	3726	7452	5181	329	194	20
G	3	2.65	3873.3	13944	2493.3	4968	9936	10481	154	174	20
H	4	3.32	4323.6	15565	2744.2	5686	11372	5181	285	60	20
L	3	2.65	5590.0	20124	5590.0	0	0	8598	282	154	0
M	4	3.32	6217.5	22383	4492.5	6210	12420	5181	329	194	10
O	2	2.65	4895.8	17625	3860.8	3726	7452	4295	213	154	20
P	5	2.65	5200.8	18723	2440.8	9936	19872	10481	213	154	0

Actual

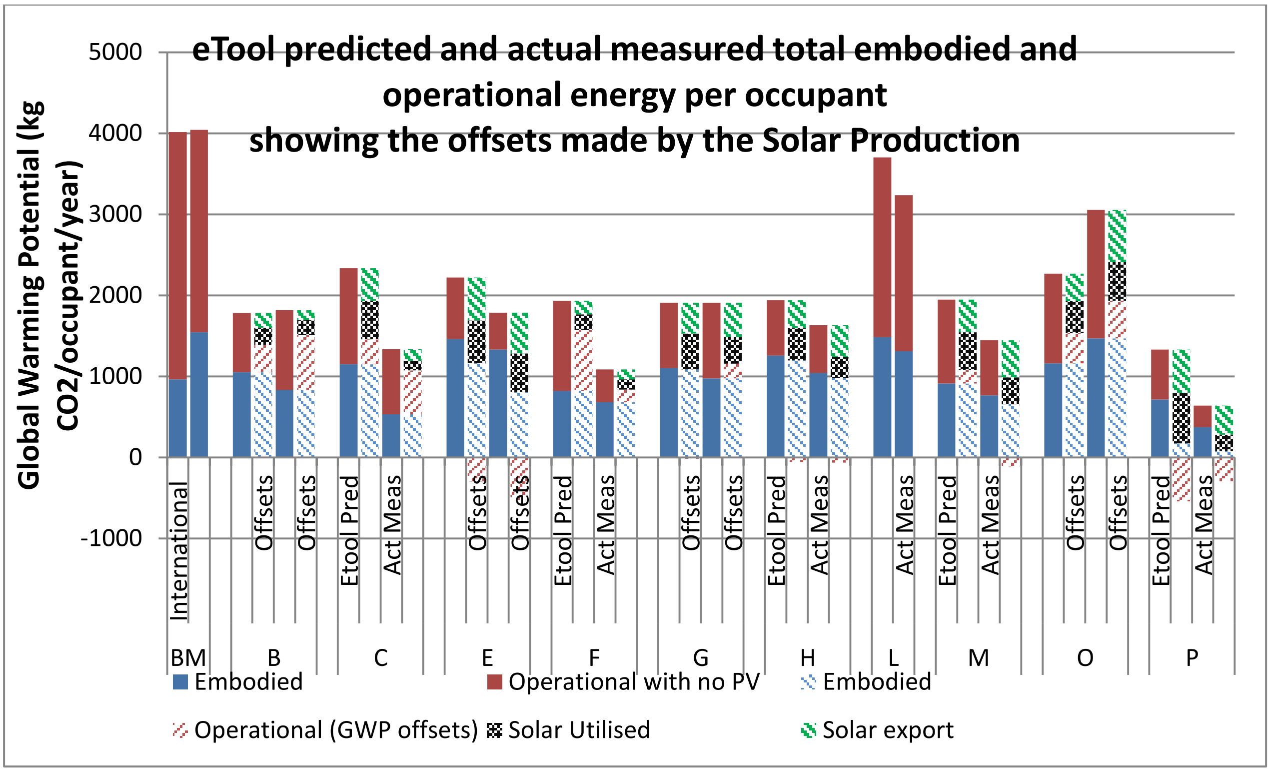
Houses	Actual Occupant	eTool Average	grid elect (kWh)	grid elect (MJ)	Solar export (kWh)	solar utilised (kWh)	Solar production (kWh)	gas (kWh)	Main Water	Wastewater	Rainwater (kL)
B	4	3.32	4034	14522.4	679	877	1556	2550	218.917	155.7832	24.433
C	4	1.85	3847.3	13850.4	789	564	1353	0	226.301	135.7806	0
E	2	1.85	1868.9	6728.0	1189	1127	2316	253	150.925	90.555	29.205
F	4	3.32	1938.8	6979.8	678	601	1279	1028	117.24	86.414	16.07
G	3	2.65	3807.1	13705.6	1744	1155	2899	2100	124.98	98.063	23.075
H	4	3.32	4249.1	15296.7	2161	1239	3400	243	245.766	169.9396	22.48
L	3	2.65	5300.4	19081.5	0	0	0	3098	277.815	166.689	0
M	4	3.32	4207.8	15148.1	2536	1581	4117	2635	202.413	133.0578	11.61
O	2	2.65	4524.4	16287.7	1775	1133	2908	1581	146.495	109.957	22.06
P	5	2.65	2478.0	8920.9	2484	1185	3669	2895	187.173	112.3038	0

Standardised

Houses	Actual Occupant	eTool Average	grid elect (kWh)	grid elect (MJ)	Solar export (kWh)	solar utilised (kWh)	Solar production (kWh)	gas (kWh)	Adj Main Water	Wastewater	Rainwater (kL)
B	4	3.32	3348.2	12053.6	679	877	1556	2117	182	133	24.433
C	4	1.85	1779.4	6405.8	789	564	1353	0	105	63	0
E	2	1.85	1728.7	6223.4	1189	1127	2316	234	140	84	29.205
F	4	3.32	1609.2	5793.2	678	601	1279	853	97	74	16.07
G	3	2.65	3362.9	12106.6	1744	1155	2899	1855	110	89	23.075
H	4	3.32	3526.7	12696.3	2161	1239	3400	202	204	145	22.48
L	3	2.65	4682.0	16855.4	0	0	0	2737	245	147	0
M	4	3.32	3492.5	12572.9	2536	1581	4117	2187	168	112	11.61
O	2	2.65	5994.8	21581.1	1775	1133	2908	2095	194	139	22.06
P	5	2.65	1313.4	4728.1	2484	1185	3669	1534	99	60	0

*eTool has a downfall in predicting rainwater yield as the amount is not directly dependant on size of the system but more likely to be dependent on the amount of times the rainwater tank can be filled and emptied throughout the year which is largely determined by the use of the rainwater.

Appendix G: Life Cycle Assessment per occupant



The life cycle assessment per occupant shows house P has almost a neutral carbon footprint as the entire operational energy per person is offset by solar production and the embodied energy is also almost offset. This is mostly due to the relatively low operational and embodied energy for a house with 5 occupants compared with the average occupants for a house with three bedrooms. The results show the embodied and operational energy per occupant is heavily dependent on the number of occupants in the house. However the number of occupants doesn't influence operational impacts such as refrigeration, heating and cooling, lighting or solar production. The houses impact per occupant will then likely change with a family of five moving out of the house and being replaced by a family of three. To be able to use a LCA as a sustainability rating, a decision would have to be made to rate the house based on the expected number of occupants or the actual number of occupants, alternatively per dwelling or per square meter as expressed in the study would be the preferred method.

Appendix H: Life Cycle assessment result breakdown for the eTool prediction of each house

eTool Predicted										
Global Warming (kg CO2-eq/Dwelling/year)	E	G	F	B	L	P	H	O	C	M
Products	1,385.30	911.2	1,057.60	1,707	1,913	563.3	2,314	1,198.20	593.5	1,309.80
Transport	316.1	266.6	368	474	539	225.4	564	381.1	323.4	350.8
Construction	61.8	102.7	84.8	111	105	90.5	119	92.9	92.9	78.5
Recurring	513.3	1,183.30	667.7	711	832	593.2	724	775.3	681.4	838.4
Energy	1,878.20	2,726.20	3,534.90	2,480	5,220	2,522.50	2,654	3,337.70	2,404.70	4,004.10
Water	505.4	408.1	699.1	545	655	530.8	762	493.3	545.5	756.6
End of Life	517.7	534.7	658.6	585	644	464.9	610	700.2	517.4	566.2
Energy Export	-979.2	-1,002.20	-550.2	-600	0	-1,419.20	-1,140	-900.3	-750.3	-1,330.40
Product Reuse	-90.3	-75.5	-107.2	-102	-99	-48.2	-168	-72.5	-87	-112.7
Total	4,108.30	5,055.20	6,413.30	5,910	9,810	3,523.30	6,438	6,005.80	4,321.40	6,461.10

Appendix I: Gantt chart