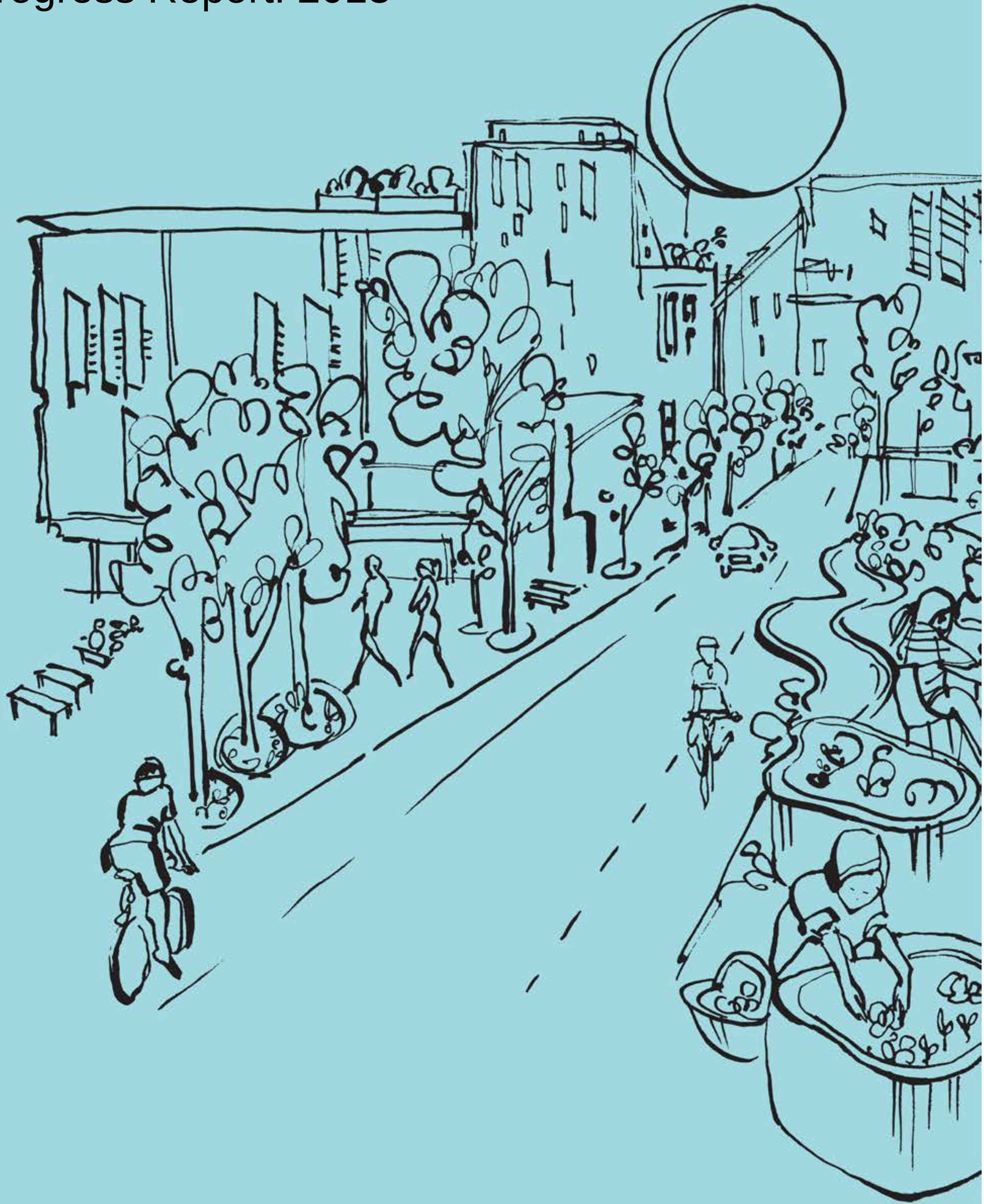
LOW CARBON LIVING CRC

RP1006: Viable integrated systems for zero carbon housing

Progress Report: 2013



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Disclaimer

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Acronyms

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BASIX	Building Sustainability Index
BCA	Building Code of Australia
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CSH	Code for Sustainable Homes
EPI	environmental performance index
HEEP	Home Energy End-use Project
HERS	house energy rating scheme
HVAC	heating, ventilation and air conditioning
LEED	Leadership in Energy and Environmental Design
NatHERS	Nationwide House Energy Rating Scheme
RBEE	Residential Building Energy Efficiency
REMP	Residential Energy-Monitoring Program
SAP	Standard Assessment Procedure
ZCH	zero carbon housing
ZEB	zero energy buildings

Executive Summary

RP1006 has been established to support the path to zero carbon housing (ZCH) by focusing on the development and validation of evidence-based building energy modelling tools to support the regulatory pathway to zero emission housing in Australia. The initial milestones, being a scoping study of available house energy rating tools and a scoping study of residential energy end-use monitoring, have successfully been completed. In addition, a stakeholder workshop was held to investigate what research will be needed to facilitate the transition to viable zero carbon housing. On the basis of the information gathered and interaction with the stakeholders, the recommended activities of the research program including key functionality for the proposed tool are established.

House energy rating tools

The scoping study on house energy rating tools has identified and examined a number of building energy simulation packages and building environmental performance indexes used in Australia and internationally. In particular, the report investigates BREEAM and SAP from the United Kingdom; LEED and EnergyPlus from the United States; plus GreenStar, BASIX and NatHERS from Australia.

Whilst, the knowledge gained from examining domestic and international tools is invaluable, it was found that no existing tool was applicable for use in the Building Code of Australia to test compliance to a zero carbon housing standard. A significant program of work in RP1006 will be required to develop and validate a suitable ZCH design tool for the Australian market.

Residential energy use monitoring

The scoping study of residential energy end-use monitoring has identified a large number of monitoring exercises that can provide data for the development and validation of the proposed ZCH design tool. The rapid rate of technology development and change in lifestyle aspirations means that many pre-2006 studies provide information about outdated technology, atypical building designs and pre-digital age occupant behavioural patterns.

The study found that we do not have sufficient evidence about the energy performance of the range of building types, technologies and user behaviours to build detailed models of building energy use in all relevant climates covering the Australian continent. Further data collection from 'Living Laboratories' will be necessary to supplement existing data.

Introduction

Energy use in residential buildings is a significant contributor to anthropogenic greenhouse gas emissions. RP1006 has been established to support the path to zero carbon housing (ZCH), focusing on the development and validation of evidence-based building energy modelling tools to support the regulatory pathway to zero emission housing in Australia.

Stage 1 of RP1006 includes 2 key milestones to be completed in the 2012/13 research period.

Milestone 1: National building energy use database

- Target 2012/13 - Scoping study of available empirical evidence

Milestone 2: Develop holistic, system integrated ZCH design tool

- Target 2012/13 - Scoping study of Australian and international tools

This report fulfils the requirements of these milestones. In addition, a stakeholder workshop was held on 14 May 2013 to discuss the scope of research needed to facilitate the transition to viable zero carbon housing. A summary from the workshop is provided in Appendix A of this Progress Report.

A further deliverable from the year 1 program is a report summarising the results of 2 year detailed energy monitoring program being carried out at the Lochiel Park Green Village. This is provided in a separate accompanying report.

The structure of this report has been designed to introduce the concept of building energy/carbon design tools; explore the various types and brands in common use both in Australia and internationally; and finally examine the evidence base available to support the further development of zero carbon housing design tools in Australia. In particular, this report identifies some of the evidence gaps that will need to be addressed to facilitate the development of those tools.

Background

Energy efficient and renewable energy technologies have been applied in buildings to improve thermal comfort and to provide water heating for centuries [1]. During the past few decades these and other technologies have demonstrated the potential to achieve extremely low energy performance, with well-known examples such as the University of Delaware 'Solar One' built in 1973 [2], the Freiburg Solar House built in 1992 [3], and BedZED, which was completed in 2002 [4]. Recently the increased availability and affordability of renewable technologies has encouraged larger numbers of building practitioners and researchers to create homes that have little or no net energy or carbon impact, with the International Energy Agency's "Towards Net Zero Energy Solar Buildings" project mapping almost 300 net zero energy and energy-plus buildings worldwide [5]. The rapid move to ultra-low energy buildings has also been accompanied by a variety of different calculation methodologies using different boundaries to determine the relative energy and/or carbon impact [6].

The rapidly growing number of exemplar buildings and developments demonstrating industry's capability to deliver low energy housing has given governments the confidence to propose building energy regulation at levels approximating net zero energy or net zero carbon [7, 8]. In the United Kingdom, the national government has set the regulatory target of net zero carbon for new dwellings by 2016 [9], in Europe the EU Directive on the Energy Performance of Buildings [10] specifies that by the end of 2020 all new buildings shall be 'nearly zero energy buildings' [11]. In other developed nations such as the USA and Australia, policy makers have suggested the need to move to net zero energy buildings by the 2020s [11, 12]. Matching this policy fervour, many definitions have been proposed for net zero energy homes [6, 11, 13, 14].

In parallel, a variety of building energy rating tools, schemes and labels such as the ‘Code for Sustainable Homes’ in the UK [15] and ‘Minergie-A’ in Switzerland [16] are being developed to assess compliance with the net zero energy standard. Many other building energy rating tools including energy-use simulation tools are being used to influence various design aspects for net zero energy buildings [17].

In Australia a star rating system driven by the Nationwide House Energy Rating Scheme is used to evaluate the thermal comfort energy requirements with 10 stars implying the building providing comfort without mechanically driven heating and cooling [18], whilst in NSW the planning instrument BASIX is used to evaluate the energy, water and carbon impact of proposed new dwellings. Neither of these tools are designed to assess compliance to a net zero energy or net zero carbon building regulatory standard, therefore significant development will be necessary to prepare and validate a suitable building energy rating tool for demonstrating compliance of ZCH in Australia.

The success of any ZCH design tool will depend on the accuracy of the analysis performed and the confidence stakeholders have that the analysis represents the best available mathematical models, validated by comparisons with actual building performance data [19]. While it is recognised that ZCH design tools can be used for non-regulatory purposes, such as optimising a building for specific goals to reducing energy use, greenhouse gas emissions and peak demand, or investigating the impact of particular design changes, this paper will focus on the use of ZCH design tools for regulatory purpose. That is, the use of ZCH design tools to satify the requirements of the Building Code of Australia or equivalent planning standards.

Types of house energy rating tools

There are two main classes of assessment tools used to measure or communicate the energy and/or carbon impact of residential buildings. Firstly, building energy simulation tools (e.g. EnergyPlus, AccuRate, ESP-r) are used to model the building elements and associated energy systems to determine likely energy use and generation given certain assumptions of climate and user behaviour. Secondly, environmental performance indexes (e.g. GreenStar, BREEAM, LEED) are used to compare buildings according to a range of expected impacts, weighted according to the relative importance of a subset of environmental issues in that region.

There are many building energy simulation tools available in the market. Crawley et al. [20] compared a subset of 20 building energy simulation tools, noting that hundreds of similar software programs existed. Kavgic et al. [21] and Attia et al. [17] provide an appraisal of many of the most popular bottom-up physics based models using various simulation engines including BREDEM (SAP) and ECOTECT in the United Kingdom, HOT200 Batch energy simulation program in Canada, DOE-2 in the United States, and VerbCO2M in Belgium, whilst the US Department of Energy provides a directory of over 400 building energy software tools.

A key difference of relevance to this report is that building energy simulation tools are commonly used to test compliance with mandatory building energy regulation; whilst environmental performance indexes are typically used to differentiate buildings for marketing purposes or voluntary standards.

Building energy simulation tools

Engineering based building energy assessment is used in many countries to demonstrate compliance with building regulation [18, 22-25], and have been influential in shaping building regulatory standards [26-29].

In the United Kingdom building energy regulation utilises the software model Standard Assessment Procedure (SAP) to determine the relative energy efficiency merits of home design [25]. Similarly, in the United States of America DOE-2 and more recently EnergyPlus thermal performance predictive software developed by the US Department of Energy can be used to determine fitness against local building energy regulation.

In Australia, software tools from the Nationwide House Energy Rating Scheme (NatHERS) are used in the building regulatory framework to predict annual heating and cooling energy loads [18], in a similar way to SAP in the United Kingdom. NatHERS tools differ from SAP in that 2nd generation NatHERS tools incorporate a full thermal simulation model whilst SAP is a simple heat balance calculator which does not take into account the dynamic interaction of climate, building characteristics and occupants [30]. BASIX, although not a simulation tool, allows building energy simulation from NatHERS tools to be used as an input into the thermal comfort calculation of the environmental performance index.

NatHERS/AusZEH Design

The Nationwide House Energy Rating Scheme (NatHERS) was established by the Ministerial Council on Mines and Energy in the early 1990s as a means to encourage increased thermal comfort in Australian homes [31]. The scheme assigns a star rating (originally to 5 stars and later to 10) to dwellings derived from a calculation of the sum of annual heating and cooling energy theoretically required to maintain human thermal comfort within particular bounds for a standardised household profile. The NatHERS scheme uses a set of published assumptions on the way buildings are constructed and operated [32]. Standardised comfort settings, internal thermal loads and household behaviour patterns allow comparisons between buildings rather than comparison between occupant behaviours.

NatHERS is designed to communicate the potential for a dwelling to have low energy requirements for heating and cooling, and does not calculate the energy used for lighting, water heating, cooking, laundry or general plug loads. The NatHERS scheme does not calculate actual end-use energy consumption as it doesn't consider: (a) the full range of energy consuming activities; (b) the efficiency of the heating or cooling equipment; or (c) the behaviour of the actual household. NatHERS ratings are limited to the theoretical impact of the house design and construction (materials) on human thermal comfort for an average (and defined) occupancy pattern.

The hourly energy requirements to maintain thermal comfort in each building space are calculated using computer simulation against a typical meteorological year and using known qualities of building materials. Originally a software package to calculate the energy requirements and report the results and the star rating, also called NatHERS, was developed by CSIRO and adopted for the scheme. This NatHERS software, now superceded, is regarded as a 1st Generation NatHERS tool to recognise the later substantial reform of the scheme and the associated calculation engine.

There is often confusion about the scheme and the identically branded software tool. The NatHERS scheme determines:

- the parameters of energy coverage;
- thermal comfort parameters;
- internal heat energy loads associated with appliances, equipment and people;
- the standardised occupant behaviour profiles;
- the manner in which the spaces are zoned (defined);
- the manner in which the spaces are conditioned;
- zones of equivalent climate and the associated weather files;
- building material performance characteristics;
- the metrics for performance description (MJ/m2, Stars); and
- maximum performance values for Star levels.

During the development of energy efficiency provisions of the Building Code of Australia in the early 2000s significant stakeholder dissatisfaction on the limitations of the original CHENATH engine lead to agreement by Ministerial Council on Energy's Energy Efficiency and Greenhouse Gas (E2G2) committee that a number of improvements to NatHERS be made as a matter of priority. The improved Scheme and calculation engine were released as 2nd Generation NatHERS in 2006.

NatHERS compliant software allows the building to be described (design, construction, location) and uses the standardised data and protocols to calculate the energy needed to maintain thermal comfort for average occupants. The scheme allows for any number of alternative compatible software tools and tests compatibility using a sample of house designs against the CSIRO developed reference tool 'AccuRate'.

Recently CSIRO has created two new tools built on the CHENATH calculation engine. The AccuRate Sustainability branded tool has extended the capability of NatHERS software to examine additional environmental impacts including: hot water energy use, lighting energy use, embodied CO_2, and water use. These modules are not sufficiently validated to be used to test compliance with BCA requirements for lighting, hot water or any future change towards ZCH. The AusZEH Design is a home design/retrofit tool aiming to predict whole of house energy consumption. AusZED Design extends coverage to include: energy used by fixed appliances and plug-in appliances; and energy generated by renewable energy systems; and allows variations to home occupancy patterns. This tool facilitates the examination of what-if scenarios, such as assessing the economic payback of changing appliances or some building fabric elements (eg insulation). AusZED Design can not be used for regulatory purpose.

The NatHERS CHENATH engine remains the most scientifically rigorous tool to calculating household energy use in Australian conditions, and may provide a useful starting point for the proposed ZCH design tool.

DOE-2 and EnergyPlus

The US Department of Energy has developed a succesion of thermal performance predictive software designed to be used to determine fitness against local building energy regulation. Building energy assessment tools such as DOE-2 and more recently EnergyPlus have been employed to test building regulatory compliance.

DOE-2 is a building energy simulation tool which uses a description of the building layout, constructions, operating schedules, energy systems (lighting, HVAC, etc.) and utility rates, along with weather data, to perform an hourly calculations of likely average building energy use, and to estimate utility bills.

EnergyPlus has evolved from DOE-2, and is designed to model the energy and water use in both residential and commercial buildings. EnergyPlus calculates heating, cooling, lighting, ventilation, and other energy flows; and water use.

SAP/BREDEM/CSH

BREDEM consists ofa series of heat balance equations and empirical relationships to produce an estimate of the annual (BREDEM-12) or monthly (BREDEM-8) energy consumption of an individual dwelling. A modified version (BREDEM-9) forms the basis of the UK Government's Standard Assessment Procedure (SAP) which is used as a compliance path for UK building energy regulation. In addition to assessing energy use for thermal comfort, SAP/BREDEM determines the electricity use for lights and appliances using simple relationships based on floor area and occupant numbers.

In light of the policy move to net zero carbon homes, the Code for Sustainable Homes (CSH) tool has been developed to test compliance with the energy provisions of the UK Building Code [15, 33]. The CSH covers nine categories of sustainable design although all nine are not compulsory:

- Energy and CO2 emissions
- Water
- Materials
- Surface Water Run-off
- Waste
- Pollution
- Health and Wellbeing
- Management
- Ecology

CSH has evolved from BRE's EcoHomes system which draws on SAP/BREDEM for energy and CO2 emission calculations.

Figure 1 NatHERS logo

Building environmental performance index tools

Environmental performance index tools are designed to allow buildings to be rated and compared on a range of environmental indexes, rather than calculate the likely annual energy or carbon impact of that building. Each environmental impact is weighted according to a value judgement placed on the relative importance of that issue for the location. For example: BREEAM Gulf (designed for the Arabian Peninsula) places a higher weighting on theregionally important issue of water, compared to BREEAM UK where water issues are relatively less important.

Popular tools include BREEAM in various regional versions, LEED in the USA, and GreenStar in Australia,

BREEAM

The Building Research Establishment Environmental Assessment Method (BREEAM) is a UK-based scheme launched in 1990. BREEAM is the world's longest established and most widely used method of assessing, rating and certifying the environmental performance of buildings. Similar to LEED (see next section) it measures building performance against benchmarks, both in the design phase and post-construction, as well as including life cycle analysis in the accreditation process. Both schemes have different rating systems for different types of buildings; office, education, industrial, etc. BREEAM has been updated several times since its inception, for example, moving in 2008 to mandatory post-construction reviews of building energy performance. BREEAM's energy performance criteria are based on UK building regulations.

The UK Building Research Establishment (BRE) has collaborated with agencies in other countries to export the system and its standards (e.g. BREEAM Gulf on the Arabian Peninsula, BREEAM NL in the Netherlands, BREEAM SE in Sweden), with a higher weighting placed on regionally important issues. Some local planning authorities in the UK encourage or specify various levels of BREEAM certification for building projects over which they hold approval status.

BREEAM examines the sustainability implications of building a house as well as the house's energy performance. Points are allocated against 9 categories listing environmental and social impacts of the construction, and a rating is awarded based on the total of points. For general buildings the ratings are; Pass (≥ 30% of available points), Good (≥ 45%), Very Good (≥ 55%), Excellent (≥ 70%) and Outstanding (≥ 85%). A tiered system of minimum standards must be met to qualify for each level of rating. The following tables (Table 1.1,Table 1.2) taken from [34] lists and compares the assessment areas of BREEAM and LEED. Note that while the first five categories are broadly comparable, they differ in the detail of issues covered within the category.

The weightings applied to each category are agreed upon by a panel of experts and industry stakeholders. Buildings rated Excellent or Outstanding must undergo an in-use assessment within 3 years of construction to retain the rating. They also must supply data on their performance for the use of BRE. The assessment is carried out by third party trained assessors. As an example of the type of topics considered under the category of transport, credits can be earned for: connectivity to the existing public transport network, adjacency to existing amenities, provision of facilities for cyclists and pedestrians, limiting of car parking spaces, and having transport plans for individuals.

LEED

The Leadership in Energy and Environmental Design (LEED) rating scheme is a program of the US Green Building Council, dating from the late 1990's. Although LEED was originally focussed on office buildings, it included a rating tool for new house construction in 2008. This program takes a wide view on the sustainability of housing; assessing a project across 8 environmental categories (the first four have minimum mandatory standards). The categories for homes are: sustainable sites, water conservation, material and resource efficiency, indoor environmental quality, energy and atmosphere, awareness and education, innovation and design, and location and linkages.

LEED for homes has 4 levels of certification; 45 points are a pass (with 18 points from mandatory requirements), silver 60 to 74, gold 75 to 89, platinum 90 to 136. Incorporation of regionally important issues can earn bonus points.

Auditing includes; verification of mandatory items through review of documentation, site inspections and performance testing. Energy performance criteria are related to ASHRAE standards. Auditing is by accredited professionals.

LEED's technical criteria, including the weighting awarded each category, are set and publicly reviewed by members of the US Green Building Council.

Table 1.1 Assessment Areas for BREEAM 2011

Environmental Section	Weighting
Land Use & Ecology	10%
Water	6%
Energy	19%
Materials	12.5%
Health & Wellbeing	15%
Transport	8%
Waste	7.5%
Pollution	10%
Management	12%
Innovation (Additional)	10%
Total	110%

Table 1.2 Assessment Areas for LEED 2009

Environmental Category	Weighting	Max. points
Sustainable Sites	23.6%	26
Water Efficiency	9.1%	10
Energy & Atmosphere	31.9%	35
Materials & Resources	12.7%	14
Indoor Environmental Quality	13.6%	15
Innovation in Design	5.5%	6
Regional Priority	3.6%	4
Total	100%	110

GreenStar

Green Star is an Australian system of certification for the design and construction of environmentally sustainable buildings, fitouts and communities. GreenStar is wholely owned and managed by the Green Building Council of Australia (GBCA).

Although the GreenStar certification system can not rate individual houses, the GBCA released the Green Star - Multi Unit Residential rating tool in 2009 to promote the design and construction of high-performance green residential developments. Recognised assessments using GreenStar tools must be completed by GBCA certified Assessors, with the commensurate fee paid to the Green Building Council of Australia.

The technical criteria including weightings are overseen by the GBCA Technical Working Group, a voluntary collaboration of environmental and industry experts.

BASIX

The Building Sustainability Index (BASIX) is a planning instrument used in NSW to measure a proposed development against various energy and water performance targets that are based on the regional home benchmark average. Although BASIX fundamentally an environmental performance index, it allows inputs from NatHERS building energy simulation tools to provide a more detailed analysis of thermal comfort related energy use.

Building energy standards

Energy standards such as Passivhaus are not building simulation or environmental performance index tools, but instead draw on the results of building energy simulation tools to test compliance to a particular performance level. The primary purpose of standards such as Passivhaus is marketing, although the specific performance level can be embrassed within building regulatory standards.

Passivhaus

Passivhaus is a building energy efficiency standard developed in Germany from the early 1990s. The Passivhaus-Institut claims around 30,000 buildings have been certified as of 2013, mostly in Germany and Austria. Many are new residential buildings but the PassihausUK website has examples of offices, terrace housing and a community centre that meet the standard.

Passivhaus focuses on minimising buildings' primary energy use as the balancing indicator, as for many other energy calculation systems. The advantage of conversion into primary energy is that the varying energy expenditure involved in providing the electricity is also taken into account. On the other hand, it is also noted that a disadvantage is that it does not necessarily show a direct link with costs to the home occupant, and that primary energy factors for different fuels need to be established depending on location of the home. Passivhaus requires a building with excellent thermal performance, a low rate of air leakage, and where additional heating is required, mechanical ventilation using heat recovery systems. Renewable energy generation is not included in the certification analysis. The standard's initial target figure is on heating power and space heating demand. Passivhaus is essentially encapsulated in just three numbers:

- Projected primary energy demand must be at most 120 kWh/m2 per annum; this includes energy use for space heating and cooling, domestic hot water, lighting, fans, pumps and typical appliances
- The peak heat load must be designed at most 10 W/m2, or heating and cooling demand must be at most15 kWh/m2 per annum for each.
- An in-situ blower door test must confirm an air tightness of at most 0.6 times the house volume per hour at 50 Pascals (positive and negative pressure)

Passivhaus has its own software, based on an MS Excel spread sheet, which must be used along with approved regional climate data to verify the energy load of a building. Assumptions of the modelling include: internal heat sources produce 2.1 W/m2; the occupancy rate is 1 person per 35 m2 of floor area; domestic hot water demand (at 60°C) is 25 litres per person per day; and air flow averages 20 to 30 m3/h per person. Certification is mainly a desk audit of information supplied by the proponents, accompanied by on-site testing of air tightness and verification of the performance of the ventilation system.

Residential energy use monitoring

What evidence do we need?

The development and validation of a holistic, system integrated ZCH design tool to support the regulatory pathway to zero emission housing in Australia will need to be anchored by a stong foundation of empirical evidence.

Building energy simulation tools typically draw upon libraries of building materials and systems and their physical properties, databases of local climate, assumptions of internal heat loads (i.e. cooking, lighting, etc.), and assumptions of human behavioural responses, use patterns for different room types and appliances, the operation of building systems (i.e. windows, lights, etc.) and furnishings such as blinds and curtains [32]. Since building certification occurs before occupancy, all assumptions of occupants and occupant behaviour should represent the average use over the building's effective life. The result is a calculation over a period of time, usually 12 months, of the amount of energy needed to maintain thermal comfort and other energy services for a defined average household under a typical year weather conditions. When combined with appliance use patterns and efficiency information for the specific installed technologies, the final result is an estimate of the energy consumed and in cases where renewable energy technologies can be applied, the calculation includes an estimate of energy generated (usually solar and/or wind).

If we take as an example the evidence requirement for 2nd generation NatHERS tools, these software packages input typical meteorological year weather data for around 70 climate zones. They draw on building product databases, internal heatload profiles, and a common set of assumed household user behaviour patterns to allow fair comparison between dwellings at the building approval stage [32, 35, 36].

Validation of the NatHERS building energy model has been limited to comparisons with results from other models, monitored energy consumption of individual buildings without households, or at best small samples of buildings with households [37-41]. These validation exercises have involved a range of construction types (timber, brick veneer, cavity brick, and mud brick) and have been conducted in various climates including cool temperate, temperate, warm temperate and hot humid climates. While these validation exercises have found that in general NatHERS tools are reasonably accurate at assessing the indoor environment and estimating the energy required to maintain thermal comfort for the occupants, studies such as Saman et al [40] have identified specific weaknesses in household behaviour assumptions. Validation processes on both 1st and 2nd generation NatHERS tools have been tested against the BESTEST protocol, developed by the International Energy Agency for evaluating building energy simulation software [37]. The BESTEST process compares the results of simulation runs against the results produced by eight benchmark software tools, and NatHERS tools have been found to be consistent with the benchmark tools within the protocol's acceptable tolerances in the physics adopted.

The process of validating the NatHERS building energy model against large samples of occupied buildings has occurred infrequently as few large post-occupancy energy consumption studies have been undertaken in each of the climate zones to the required technical standard. Research on smaller samples of occupied houses has found that individual household energy consumption varies greatly when compared to the theoretical models used in NatHERS software tools [40, 42]. Typically the difference between the energy consumption calculated by the theoretical energy models and actual energy consumption is largely caused by the great variety of occupant behaviours and building usage patterns [40, 43-49]. It should be recognised that energy rating software is not intended to predict the actual energy consumption of any specific household, but rather is intended to represent the energy-use performance of an average or typical family under certain conditions. These rating tools are primarily used to allow comparisons between the inherent qualities of building designs and energy system fit-outs. When applied within building energy regulation, they can establish the minimum energy performance expectations for building designs and energy system fit-outs. This does not mean that building energy rating tools should not provide accurate assessments of average actual energy use when house sample sizes are sufficiently large and monitoring occurs over sufficient periods to reduce the impact of individual behavioural traits or unusual climate events.

Currently the building energy model used in all NatHERS certified rating tools is limited to the assessment of thermal comfort energy use. For the assessment of zero carbon homes, the building energy model will need to be extended to include the energy used for lighting, cooking, water heating and all other plug loads, plus renewable energy generation systems. Household energy consumption is affected by three main parameters, namely climate, the building and its systems, and the building users [50]. The development of credible building energy assessment tools will require sufficient evidence of energy relationships across: climate data; building materials and constructions; the building appliance and equipment fit-out; and the impact of the households.

What evidence do we have?

This section examines a selection of data collection projects which could provide evidence to support the development and validation of ZCH design tools in Australia. This brief investigation gives an indication of the additional evidence which will need to be developed in association RP1006 to ensure the accurate assessment of a home's operational energy performance.

Case Studies pre-2006

Australian household energy use monitoring

Prior to 2006 few large scale appliance monitoring programs, whole house data collection exercises, and smaller scale test cell monitoring projects were conducted in Australia of a suitable nature to support the development of building energy rating tools. The following describes the major data collection projects in Australia.

The largest appliance and equipment energy performance monitoring exercise was conducted in New South Wales and the Australian Capital Territory in 1993 and 1994 [51, 52]. Energy end-use was monitored in 290 houses at 30 minute intervals. Appliances monitored in this project included weather sensitive devices such as air-conditioners, space heaters, refrigerators, freezers and domestic hot water systems.

In preparation for the Sydney Olympic Games in 2000, the Newington village was created to house the athletes and showcase environmentally sustainable building design focusing on energy and water-efficiency. As part of a joint venture between state government and utility companies, total electricity consumption and photovoltaic solar electricity generation in 30 homes was monitored for one year from the start of July 2004 to the end of June 2005 [53, 54]. Monitoring interval was half-hourly. The aim was partly to assess the effectiveness of the sustainability features and partly to assess the impacts of residential energy use in order to reduce peak load and avoid future additional infrastructure requirement. The monitored homes were quite similar in design, construction and size, and a survey of the demographics, behavioural patterns and infrastructure condition was also conducted. No individual appliance was monitored, but from the survey the total number of appliances was collected and correlated against electricity usage.

At Mawson Lakes, a suburb of Adelaide, South Australia the gross electrical use and gas consumption was monitored in two housing clusters during the period 2001-2003, being a set of 50 houses and a set of 150 houses [55]. Between April 2002 and March 2003, 6 of the houses were monitored for household electrical consumption in all major electrical circuits, gas usage, and hot water consumption. Associated demographic data which may affect energy usage such as number of occupants, house floor area, main house design features and major appliances types were recorded. Appliances monitored included hot water system, air conditioning, lights, dishwasher, wall oven, spa, fridge/freezer, heater and general power points for plug loads.

In Newcastle, three test cell single room buildings were constructed for the masonry industry and monitored by the University of Newcastle [39]. This monitoring exercise was used to validate the 2nd generation NatHERS building energy model for brick veneer and cavity brick constructions.

Relevant International Studies

Many household energy use monitoring exercises have been conducted internationally, but due to significant differences in climate, building typology or household demographics, few are directly relevant to the development of an Australian ZCH design tool. Of particular relevance is the New Zealand Home Energy End-use Project (HEEP).

HEEP was a 10-year research program (1999-2010) that involved the detailed monitoring of energy and temperature, occupant surveys and households audits [56, 57]. 400 randomly selected households were recruited. Data collection started in 1999 progressively as houses were recruited and ended in 2005. The monitored period varied house to house with the majority monitored for a twelve month period while others were monitored for two years. The monitored energy source included gas, electricity, wood, LPG, coal, oil, and solar water heating. The scope of energy sources covered makes this project fairly unique when compared to many other household monitoring projects. 74% of the houses had total load monitoring which includes all fuels used in the house, while 26% of the houses had detailed end-use monitoring. Monitoring interval was 10 minutes or less. Three of the houses had smart meters installed and these provided 60 second interval data. Some appliances such cooking ranges and hard-wired electric heaters were monitored in a circuit. Plug-in loads were monitored via having transponders attached to the appliance itself. Indoor temperature was monitored in two living spaces and in at least one bedroom.

Appliance energy use data was grouped according end-use purpose: entertainment; cooking; heating/cooling; lighting; climate control; refrigeration; and either large and small miscellaneous.

Key results from the monitoring data included were:

- National average of total energy use was 11.4 GWh/year per household. The average electricity consumption per household was 3.9 GWh/year.
- Top 20 energy consuming houses used 36% of the total energy. Lowest 20 energy consuming houses used 9%.
- Electricity provided about 70% of all energy monitored. Solid fuel (wood or coal) which provided 20% of energy, which was higher than previously estimated. Gas supplied only 9% of the total energy needs.
- Space heating is the largest energy user (34%), followed by water heating (29%), refrigeration (10%), lighting (8%). Smaller miscellaneous appliances use 13%. For electrical appliances, refrigeration topped the list at 27% of total electrical energy use, followed closely by lighting at 23%. Entertainment equipment including computers, laptops, videos, games, and spa pools, was the next highest at 18%.
- Solid fuel is the most predominant space heating fuel in New Zealand at almost 56% of total energy used for space heating, followed by electricity at 24%. Gas space heating is at just 14%.

A wide range of research projects came out of the monitored data. One key outcome was the development of a database to store the monitored and surveyed data in a way that could enable users to utilize it to their benefit. HEERA, the Home Energy Efficiency Resource Assessment model/database, was developed out of the data from the monitoring results to determine the appliance, building stocks and their energy demand in dwellings. Dwelling and appliance stock algorithm, and energy use algorithms for the different end-uses were devised to show relationships, variables and drivers of energy use by appliances. The result provided a model of end-use per dwelling, factoring in appliance stocks per dwelling and energy consumption per unit appliance, which is the product of a whole range of occupant economic, social demographic characteristics and behaviours.

The data also fed many multi-disciplinary projects on the various impact of energy use. A thorough analysis on winter and summer temperatures in the house have resulted on studies from the cooling and heating behaviours of occupants, thermostat settings, heater type and fuel used, to the age and quality of housing, diurnal temperature variation of the houses , all the way to the health impacts on occupants, especially pensioners. Fuel poverty was a key research issue, revealing the financial impacts of fuel switch and costs on the low-income householders. Hot water and water consumption was examined in detail with the data identifying a relationship between house size, energy use, water use, resource required and costs. Since solid fuel was a predominant space heating fuel in New Zealand, a new, practical method was established to calculate how much delivered heating output has been developed using the monitored temperature and energy data. The method derived at the amount of energy input and the heating output from solid fuels for all houses being 20% of all energy used in the residential sector, a significant finding which may change government policies.

Although these Australian and international studies provide useful information about energy use of appliances and buildings of various construction types, the age of the data and the types of technologies measured limit their usefulness to the development of a ZCH design tool. Fundamentally, the rapid rate of technology development and change in lifestyle aspirations means these studies provide information about out-dated technology, building design standards and occupant behavioural patterns.

Post-2006 Case Studies

A renewed policy interest in building energy performance combined with the increasing cost effectiveness of data monitoring and communication equipment has contributed to a growing number of building energy monitoring exercises in Australia since 2006. Various household appliance [58], test cell [41, 59] and whole building monitoring projects [60-63] have been conducted in a range of Australian climate regions.

Currumbin Eco-village, Queensland

In sub-tropical south-east Queensland energy monitoring of 45 non-air-conditioned homes within an eco-village commenced in 2009 and is ongoing. The monitoring includes 2 temperature sensors, a humidity sensor in the main living space, and electricity consumption and generation data at 1 minute intervals. Electrical consumption can be further disaggregated into 3 categories: lighting, refrigeration and general power (excluding water pump, ceiling fans, cooking, space and water heating). A demographic survey and interview of a subset of occupants was conducted to determine their awareness and expectations of comfort [60]. As none of the houses had air conditioning units installed, no energy usage for cooling is available. In order to determine whether comfort has been achieved, occupant surveys and examination of indoor temperatures are the main instruments. This particular type of non-air conditioned eco-house, is not typical of housing in the local climatic region. The breakdown of energy use is limited, with ‘general power’ including a range of appliances.

REMP, Melbourne, Victoria

For the period May 2010 to April 2011, the Residential Energy-Monitoring Program (REMP) monitored 5 existing houses in Melbourne. Items separately monitored included 12 lights, up to 16 appliances, whilst all other appliances were monitored together as general plug loads [58]. Also installed were humidity and temperature sensors (both internal and external), in-line gas and water meters, occupancy sensors in major living rooms and hot water temperature sensors. Each house contained about 60 loggers. Ambient weather conditions and simple products were logged every 10 minutes, while devices such as heating, cooling and refrigeration were monitored at an interval of every 1 to 2 minutes. No detailed information on the building demography was surveyed, limiting the potential for correlations with building type, design features or construction methods. Due to the small sample size and limited scope of the pilot data, the project serves more as a demonstration of what detail monitoring potentially could provide.

Test Cells, Launceston, Tasmania

In early 2006, three light-weight timber framed thermal performance test cells were built in Tasmania, a cool temperate climate [41, 64]. The three test cells vary in floor construction, consisting of an unenclosed platform floor, an enclosed platform floor and a concrete slab on ground floor [59]. The thermal conditions monitored in the test cells have been compared to those predicted by the NatHERS building energy model. Two identical test cells were also built in Adelaide [65] to examine the impact of different roofing systems and insulating materials on measure their impact on the heat transmission through the roof.

Lochiel Park, Adelaide, South Australia

Lochiel Park is model green village demonstrating exemplar urban and building design principles focusing on energy and water-efficiency, with house energy performance approaching a net zero energy standard [66, 67]. The consumption of energy and water, and photovoltaic generation has been monitored since 2010 at one minute interval. The residential part of the village will eventually consist of 106 dwellings and by mid-2013, a total of 61 houses and 23 apartments are being monitored, some homes with over 3 years of data. Monitoring is expected to continue for no less than 7 years. A subset of 9 houses have itemized monitoring for the major household energy end-uses such as lighting, heating and cooling, water heating, refrigeration, oven and general plug loads. Surveys of appliance ownership, household demographics and interviews with households on a range of energy and water use issues are available for a subset of homes. Building design, construction and energy rating information is also available for all homes. In total the Lochiel Park project represents one of the largest sets of monitored homes, with comprehensive end-use and household data, over the longest time period, in Australia.

Figure 2 Lochiel Park

Heat Waves Project, various cities, Australia

Commissioned by the National Climate Change Adaptation Research Facility, a Framework for Adaptation of Australian Households to Heat Waves was a research project examining the impact of heat waves on household air-conditioning energy use [62]. Monitoring of households in Brisbane, Adelaide and Sydney covered total of 60 houses. Indoor temperatures, humidity as well as air-conditioning energy usage were monitored for 12 months between 2012 and 2013. The project incorporated pre-existing monitored data from the aforementioned residential projects in Lochiel Park and the Gold Coast.

RBEE, various cities, Australia

With data collected in 2012/13, the Residential Building Energy Efficiency project represents one of the most extensive building energy monitoring projects conducted in Australia [63, 68]. The project collects significant information about house characteristics, appliance use, energy consumption, costs and demographic in Brisbane, Adelaide and Melbourne. Covering BCA 3 main climate regions that together contain the majority of the Australian population, information for a total of 422 homes includes demographic and energy awareness surveys, house building plans, energy rating certification records, electricity and gas bills for two year period, and construction cost data. A visual inspection for compliance to the current building standard was undertaken; the energy ratings of heating and cooling equipment was collected; infra-red thermography and thermal step response tests were conducted for a subset of homes; and pressure tests were conducted in 20 houses. The houses were also re-rated to compare building thermal performance of occupied conditions against their original design rating. Energy monitoring equipment was installed in 210 houses to measure the electricity consumption on 8 circuits for each house, and temperature in the main living room was also monitored. Appliances individually monitored varied amongst sample stocks but typically included hot water system, lighting, oven, air-conditioning and general power.

Solar Water Heater in-situ Testing, Adelaide, South Australia

To examine the energy performance of solar water heating systems in-situ, a total of 27 gas and electric-boosted solar systems with both flat plate and evacuated tube solar collectors were monitored at Lochiel Park in South Australia over a period of 15 months [69]. The detailed monitoring exercise utilised a pyranometer (to measure incident radiation); temperature sensors (to continuously measure temperatures of the system hot water outlet, collector inlet and outlet water and ambient air); flow-meters (measuring hot water consumption); anemometers (measuring wind-speed across the collector to evaluate wind induced heat loss); and power or gas meters (measuring the additional energy used by the system). The in-situ monitoring was combined with TRNSYS modelling to establish realistic hot water use patterns, and to test factors such as orientation and inclination, dust accumulation, the effectiveness of pipe insulation, and the effect of shading by trees and adjacent buildings.

What evidence is missing?

Considering the range and number Australian data collection exercises, it is easy to believe that sufficient evidence is available to fully support the development of a domestic ZCH design tool. However the core issue is comprehensiveness. In simple terms, we do not have sufficient evidence about the energy performance of sufficient building types, technologies and behaviours to build accurate models of building energy use in the range of relevant climates covering the Australian continent.

Using a test for comprehensiveness for the available data collection studies:

- We know little about the in-situ energy performance for many of the technologies and systems utilised in contemporary homes
- We know little about the energy use impact of many popular and alternative building fabric construction types used in each region of Australia
- We know little about household demographics and behavioural patterns represented across the total population and their impact on energy use
- We know almost nothing about building energy use in tropical and cool temperate climates.

It should also be recognised that none of the existing research exercises were specifically designed to build the evidence base needed to develop a domestic design tool capable of testing a net zero carbon or net zero energy performance standard for building regulatory purpose, so it is not surprising that the collective evidence base from any of the studies is not sufficiently comprehensive.

Recommendations

RP1006 has been established to support the path to zero carbon housing by focusing on the development and validation of evidence-based building energy modelling tools. In particular, RP1006 focuses on developing and validating the tools necessary to support the regulatory pathway to zero emission housing in Australia.

This scoping exercise has investigated the range of house energy rating tools available both domestically and internationally, and the evidence base from building end-use energy monitoring available to improve house energy rating tools for the local housing market.

The associated stakeholder workshop was held to facilitate discussions between RP1006 Project Partners and other experts to identify the key issues and help shape the next stage of the project. The following recommendations are consistent with the workshop findings and provide a logical work program that will satisfy the intent of the original project aims.

In simple terms the project should move from the scoping process to the detailed level; and from the introductory examination of issues to the development of viable solutions. For example: the next stage of the project includes: the creation of the detailed database that holds the monitored energy end-use evidence; builds upon the evidence base with strategically important energy end-use monitoring; and commences the use of that data to further develop Australia's building energy modelling tools.

The end result should be the creation of an evidence-based building energy modelling tool (or set of tools) that utilises our increased knowledge of construction materials, building systems and energy technologies; likely household behaviour for contemporary lifestyles; and realistic weather data. Most importantly, a tool that is designed to meet the needs of all stakeholders, particularly those involved in shaping or satisfying building energy regulations.

Key functionality for the proposed tool

- Building a regulatory tool with potential to encourage best practice as well as minimum requirements
- Developing different versions of the tool for designers, product suppliers, building assessors and residents
- Inclusion of cost benefit analysis of potential intervations
- Incorporation of all fixed energy consuming appliances and systems (lighting, water heating, air conditioning, cooking, dishwasher, laundry) and allowing for other plug loads, particularly those used for entertainment and communication (refrigerators, freezers, TV, sound systems, computers, home office appliances)
- Coverage of roof top solar and other onsite energy generation systems
- Incorporation of future climate scenarios
- Inclusion of apartment specific data
- Coverage of major home renovation actions

Recommended workprogram milestones

- Develop national energy use database

The development and publication of the national building energy use database hosting household end-use monitored data from numerous pre-CRC-LCL projects and from the CRC-LCL Living Laboratories. The National database will be interrogated to establish energy use relationships and use patterns for all major household energy consuming appliances and services, and will be used to inform industry and policy makers of significant trends and potential issues. The database will host and update the evidence used to build and validate the ZCH design tool.

- Design, build and monitor low carbon homes

Knowledge generated from national energy use database will underpin the design and construction of at least three net zero carbon homes located as a part of the CRC-LCL Living Laboratories. These homes will be uniquely designed to meet the needs of contemporary lifestyles in the most populous Australian climates. The demonstration homes will be monitored for a number of years, with results captured in the national database, and with the data used to validate the proposed ZCH design tool.

- Develop building energy regulatory tool

RP1006 will develop and validate a design tool that can assess homes to a net zero carbon regulatory standard, and support the building industry in building exemplar zero energy and zero carbon homes. UniSA and CSIRO will work with industry and regulatory agencies to objectively identify the additional functionality and technical improvements necessary to extend existing tools and satisfy user confidence. The new tool will have a user friendly interface, be CAD compatible, and designed to meet international BIM interoperability standards.

- Develop economic add-on functionality to tool

An economic assessment add-on to the ZCH design tool will be created and validated in association with product suppliers, building designers and households to support decision making processes for new homes and renovations. This economic assessment functionality will also be designed to inform policy makers of the costs and benefits of low carbon homes.

- Develop renovation add-on functionality to tool

A home extension and renovation add-on for the ZCH design tool will extend the capability of rating tools to provide valuable design feedback for the large and growing home renovation market. This extension of the ZCH design tool will support homeowners and the building sector to reduce the carbon emission footprint of Australia’s 8 million existing homes.

- Dissemination and integration into regulatory process

This milestone develops the training materials, courses and information necessary to up-skill the Australian house building design and construction industry with enhanced capabilities to build low carbon homes, commission the associated energy systems, and test a building’s compliance to a zero carbon regulatory standard. RP1006 will work with industry bodies, education providers and policy makers to test and roll-out the materials, procedures and courses required to educate and train various trades and professions to deliver viable zero carbon homes.

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Appendix A: Stakeholder Workshop Summary

Project title: Viable integrated systems for zero carbon housing

Date: Friday 24th May 2013

Time: 10 am- 3:00 pm

Location: Council room, Hawke Buildings, UniSA city west campus, Adelaide

1: Project Scope: What research is needed to facilitate the transition to zero carbon housing?

a. Zero Carbon Housing requires thinking in terms of systems and materials at all levels:
   i. Aesthetics
   ii. Performance
   iii. Building type
   iv. Market
b. Sub-division design vs. energy issues.
   i. Conducting literature reviews to find out what do we already know & what more do we need to know about passive and active energy-efficient sub-division designs.
   ii. Greater understanding of the relationship between the block and house design choices. This is not normally explained to clients by project home companies. How do we determine the suitability of one housing type (eg terrace) over another?
c. Costs and paybacks associated with higher performing buildings/specifications/equipment/appliances.
d. Market research on what motivates people to ask for higher star ratings.
e. Compliance issue: Do we actually get what was designed? How do we ensure this?
f. Definition of 'Low Carbon Living' and the role of house design vs. in and out of house behaviours
g. Zero Carbon apartments/row houses?
   i. Individual units as well as whole-of-building approach.
   ii. More monitoring in apartment living is needed
   iii. AccuRate needs validating a number of assumptions for apartment living.
h. Using agreed algorithm to conduct comparisons across appliances to move to a more energy-efficient house performance.
i. Validate star rating bands in the rating tools & consider behaviour and lifestyles: confirming occupancy profiles/user profiles to validate energy loads.
j. Detailed comfort study for the various climate zones in Australia.
k. The need for a central monitoring database containing all the data from around the country.
l. A central communication point amongst the data users and amongst data owners. How to overcome the ownership barrier?
m. A centralized platform to provide client education on how to operate the building as designed, how to choose appliances etc. in a whole-of-system context.
n. A Decision Tree Tool designed for people to make their own decisions when building new homes. It needs to be simple enough to use without being overwhelmed, and be able to go into greater details when required. In the end they should be able to see how they arrived at the whole-of-system integration.
o. Collecting convincing evidences for regulatory framework of Mandatory Disclosure of building performance information.
   i. Understand market drivers for the real estate industry and devising ways to sell in relation to Mandatory Disclosure even in the case of the low-star houses
   ii. Retrofit existing homes in simple ways to prove the ease of upgrading for sale purposes. Project home clients are most at risk of inefficient homes due to the need for low costs and lack of knowledge.

2: Project Outcome: What useful project outcome should be produced for the building industry, general public and regulators to enable transition to zero carbon housing?

a. Tools to help users to determine user behaviour and occupancy themselves for the use of building rating tools.
   i. Simple tools for the general public to use themselves
   ii. Link this tool to Program 3 on social behavioural analysis
b. Improve current tools with validated monitored data.
c. Provide proofs for Mandatory Disclosure:
   i. Building the case for cost-saving building upgrades for sale
   ii. Building and proving cost/benefit equations
   iii. Building equations focusing on energy vs. comfort
   iv. Identify benefits for builders/developers: eg. Brand distinction, cost-savings, higher sale prices.
d. Improve the credibility of current tools via:
   i. Affordable post-construction building performance testing procedures
   ii. Simple methodology for compliance verification & commissioning routine

3. Other issues discussed:

a. Carbon rating and labelling on products.
b. Utilizing or re-use existing facilities in the country to develop associated manufacturing industry (eg. Obsolete car factory has the capacity to manufacture new energy-efficient products)
c. Issues on supply chain and market drivers.
d. Need for a common framework for energy monitoring eg. common time intervals
e. New data is required as some existing data is approaching 10 years old.
f. Define ways to 'measure' things that can't be numerically measured, eg. Opening of windows.
g. 3 types of tools diff inputs and outputs and rigour
h. Incorporate impact of climate change on climatic data

4: Conclusions

a. We need to incorporate appliances and on site generation
b. We need to revisit existing assumed use pattern assumptions and develop new ones on basis of monitoring evidence base
c. We need to incorporate impact on the grid
d. We need to account for impact of climate change on outdoor design conditions
e. We need different versions for new dwellings of different types and renovations
f. We need to establish gradually more rigorous regulatory and exemplary performance targets with cost/benefit analysis
g. We need different versions for designers, product suppliers, households, assessment of existing buildings, assessment of new buildings
h. We need to increase the number and details of monitoring programs