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# Building Characterisation and Retrofit Decision Support-Tools for Upgrading Homes of Low-Income Older Australians

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## Abstract

*This paper describes the development and implementation of a comprehensive methodology to select and implement energy efficiency upgrades to the homes of low-income, older (>60 years) Australians. This work was conducted as part of a project entitled, 'Energy Efficiency in the 3rd Age (EE3A)', which targeted low-income older residents in the Illawarra Region of NSW, Australia, and was funded by an Australian Federal Government 'Low Income Energy Efficiency Program (LIEEP)' grant for AUD2.3M. The project included a social marketing and behaviour change component engaging ~650 households, and a retrofit program for a subset of ~183 of these homes. Households included those from the general community (home owners) and from the aged-care sector, i.e. those living in Independent Living Units (ILUs). This paper describes the development of a unique Building Characterisation Tool to facilitate the rapid recording of up to 1,500 features of each building, which was implemented on laptops/tablets and captured information on the ways in which the occupants used their homes. A retrofit prioritisation process was also developed whereby a detailed assessment of each home was made from the Building Characterisation data. Results are also presented on the overall characteristics of the dwellings occupied by this vulnerable section of the population and preliminary results on impacts on thermal comfort, etc.*

**Keywords - Household Energy Efficiency, Retrofits, Building Characterisation, Audit, Decision-Support.**

## 1. Introduction

The importance of reducing energy consumption in residential buildings and improving comfort has been widely acknowledged by researchers, practitioners and building occupants in the past, e.g. [1]. Compared to their European counterparts, Australian governments have invested relatively little in recent times in the upgrading and retrofitting of existing homes to improve household energy efficiency and comfort levels. In Europe a significant number of programs to improve both the thermal performance of the fabric/envelope and the energy efficiency of appliances and HVAC systems

in residential buildings have been funded under various schemes. Examples include the UK Green Deal communities program [2], where £88 million was made available to local authorities for providing low energy retrofits to residential buildings; and programs from the German KfW investment bank [3] and EnSan [4] on retrofitting of a range of building types.

Despite large investments on energy retrofits in some parts of the world, thorough building retrofitting evaluation methods are difficult in practice due to the complexity of the built environment and the associated dynamics that continuously affect energy usage and occupant comfort. A notable project that gathered empirical evidence on the effectiveness of energy upgrade retrofits and their acceptability to the building occupants was EVALOC in the UK [5]. As part of this project, 27 owner-occupied dwellings underwent substantial energy retrofitting and their occupants participated in behavioural intervention activities. These case studies were intensively analysed using surveys, energy monitoring equipment and historical billing data analysis for several years before and after the retrofits [6]. Findings included that the majority of energy retrofits were reasonably effective in terms of reducing energy use and that the impact of retrofits on indoor environmental conditions and the occupants was not always positive. But for most occupants the retrofits had a positive impact on their energy usage habits. This study was then expanded to include 33 additional buildings that were not monitored as intensively as the previous 27 [7]. Important findings included that home energy improvements lead to improved comfort levels and reductions of energy consumption, but also to an increased likelihood of overheating as a result of fabric improvements.

Organisations from five European countries participated in the “Renovenergie” project [8] with the aim to analyse the processes of refurbishing residential buildings and explore the barriers and drivers to energy efficient refurbishment. Field investigations were done on 28 residential buildings and were complemented by semi-structured interviews with their occupants.

In Australia, the focus of government residential energy efficiency programs has largely been on activities including energy auditing of homes; interventions to improve lighting and appliance efficiency; replacement of hot water systems and fittings; insulation of ceilings/roof cavities (but not wall or underfloor). However, in 2012 the Australian Federal Government announced the major ‘Low Income Energy Efficiency Program (LIEEP)’ initiative to trial a wide range of new and innovative approaches to assist low-income/vulnerable households to overcome barriers to improved energy efficiency and better manage their energy use.

The research presented here was part of the ‘Energy Efficiency in the 3rd Age (EE3A)’ project funded by a AUD2.3M LIEEP grant. The project was an energy efficiency program that engaged low-income older residents in the Illawarra Region of NSW, Australia, which includes a range of

temperate climates. Core features included the project being household-centred and insight-driven through well-integrated multi-disciplinary teams, supporting multi-component interventions encompassed in a robust mixed-method evaluation. This approach placed people at the heart of the solution and provided practical processes that demonstrated an empowering alternative to “one-size-fits-all”, facilitating changes tailored to each household and their home and their practices. The project included both a ‘social marketing and behaviour change’ component with ~650 households, and a retrofit program for a subset of ~183 of these homes. Households included those from both the general community (home owners) and from the aged-care sector, i.e. those living in Independent Living Units (ILUs). A subset of ~30 of the households in the retrofit program were engaged in a more research-intensive evaluation program including comprehensive energy and thermal comfort monitoring, complemented by ethnographic insights into daily habits and behaviours.

Retrofitting elements ranging from installation of roof and underfloor insulation, through solar hot water and reverse-cycle air conditioning systems, to draught-stripping, lighting, refrigerators and energy consumption displays were installed to a value of between AUD 700 and AUD 6,000. No financial contributions were required directly from participants.

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### Building Characterisation Tool v0.1

Submit Occ. Time D. Gen. B. Ext. W. Maj. Ap. **Rooms** Min. Ap. Conc. Eval. Refl.

#### Room Inspections

This section will involve walking around the inside of the building and inspecting each room. Please mark the room numbers onto the house plan / sketch. It is advised that you use the navigation panel on the right hand side to switch between rooms and minor appliances capturing both room and appliance data before moving to the next room.

**Quick Links**

Room 02	Room 03	Room 04	Room 05	Room 06	Room 07	Room 08
Room 09	Room 10	Room 11	Room 12	Room 13	Room 14	Room 15

#### Room 1 Inspection:

**Room Type:**

**Primary Floor Covering:**

Using a laser distance measurer (preferred) or a tape measure please *measure and record the room dimensions.*

**Room Length (m):**

**Room Width (m):**

**Ceiling Height (m, Note: 2.4m is Standard):**

**Comments:**

**Navigation Panel (Right):**

- Submit
- Occupant
- Time Diary
- General Build
- External Walls
- Major Appl.
- Rooms**
- Minor Appl.
- Conclusion
- Evaluation
- Reflection

Fig. 1 Screenshot of the Building Characterisation tool interface.

## 2. Building Characterization Audit Tool

Existing Australian residential buildings have a wide range of typologies and naturally have many specific local characteristics that are a result of local construction practices, building codes and availability of materials. To provide the necessary building-specific data required to underpin a robust retrofit selection process, a comprehensive Building Characterisation Audit tool was created using a combination of HTML, JavaScript and CSS software and implemented on laptops/tablets with a user-friendly interface (Fig. 1). The architecture of the data model is shown on the right hand side of Fig. 1 and covered approximately 1,500 data fields.

The project focussed on existing buildings that had to be audited only once and in a short time period in order to avoid overly disturbing the elderly participants (1.5 to 3 hours/household). The tool included sections for capturing relevant data from discussions with the occupants (e.g. age of building, ceiling insulation levels for non-accessible attic spaces, year of installation of existing solar energy systems, etc.).

Table 1 – Summary of non-occupant related data types in the building characterisation tool

Section	Recorded data types
General building characteristics	Number/type of spaces (bedroom, kitchen, etc.); type/condition of windows/seals/shading/doors; external/internal floor types (insulation and accessibility for suspended floors); dimensions of eaves; dwelling detachment (house, unit, semi-detached, etc.); walls and roof construction/insulation/condition (e.g. structural suitability for solar HW); type/number external lights.
External walls	Orientation of external walls and external shading.
Major appliances	Metering details (meter numbers, presence of off-peak meters, gas supply, etc.); PV type, size and orientation; hot water system type/size; heating/cooling system type, capacity and controls; fridge/freezer details.
Characteristics of specific rooms	Dimensions; size/location of windows; space heating/cooling; ceiling fans; type/number of lights; ventilation (chimneys, vents, etc.), presence of mould.
Minor appliances	Details of TVs, ovens, washing machines, kettles, etc. (type, brand, nameplate power, etc.).

The second section of the tool targeted information on occupant practices (e.g. the time and number of occupants that were home throughout a typical day during different seasons) and also captured any comments from householders. In this “Time Diary” section, information was also collected on daily schedules of activities that could affect energy consumption and comfort levels, e.g. opening windows, use of lighting, cooking, appliances, and heating/cooling systems, and times of showers and sleeping. The

remaining sections of the tool captured building-specific and appliance information. Table 1 summarises the types of technical data that were collected during a home audit.

Provisions were also made to record any health and safety concerns, and reflect on the success of the household audit visits. The final outcome was a rich dataset for each household from which a report was automatically generated and used in the retrofit selection process described in Section 3.

### 3. Retrofit Selection and Implementation Process

Following the auditing of ~200 homes, a retrofit assessment/implementation process was developed whereby a detailed assessment of each home was made using the Building Characterisation data, and a set of retrofits prioritised generally from a short-list of 18 possible options. The final installation of the retrofits was then carried out following a rigorous budgeting and prioritization process and face-to-face consultations with each household and signing of legal agreements.

**Retrofit Assessment Process:** the first step was to undertake a preliminary assessment of major energy usage pathways in the home. Electricity and gas bills were reviewed, comparing daily consumption for summer and winter to gauge heating and cooling energy consumption. If an ‘off-peak’ electricity meter was available this was used to assess the proportion of energy used for hot water. Heating and cooling questionnaire data was used to complement/verify this preliminary assessment.

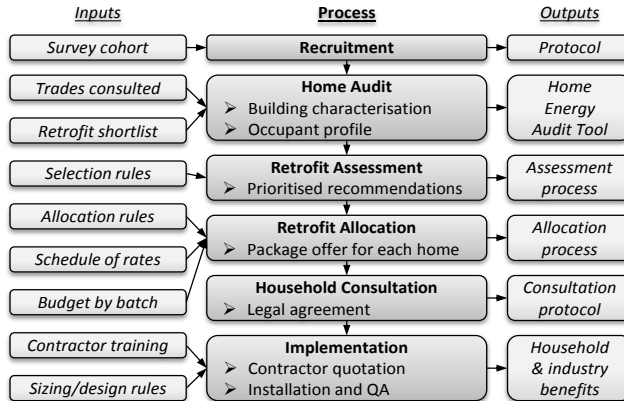


Fig. 2 Household-centred retrofit selection and implementation process.

A detailed assessment of each shortlisted retrofit was then carried out for each home against a set of staged criteria including the following:

1. Eligibility: ownership restrictions; age of existing (>10y) systems; etc.
2. Technical feasibility, e.g. adequate structure support; space; WHS.

3. Cost-benefit weighting: purchase cost; installation cost; cost to make good existing support services and structures; likely utilisation.
4. Co-benefits: thermal comfort; health, age, mobility; mould issues; social capacity building; householder desire for the retrofit.
5. Recommendation: householder retrofit requests; auditor comments; assessor recommendation; peer review recommendation.

These criteria were melded with retrofit requirements resulting in a matrix of 240 questions for each home, implemented as a spreadsheet Assessment Pro-forma. Fields were filled through a combination of auto- and manual-processing of audit tool data and photos. The formal assessments were carried out by the present authors and typically took ~1.5 hours, followed by a formal peer review process for quality control. Retrofit technologies were shortlisted in groupings to assist in allocation of packages within common building tradesperson skills, i.e. thermal envelope: ceiling and sub-floor insulation; draught-proofing; major fixed appliances: hot water; reverse cycle air conditioning; window treatments: internal cellular blinds; external shading; electrical: ceiling fans; AC standby switch; energy display; appliances: fridges and freezers; clothes dryers; minor supplementary items: lighting; hot water pipe lagging; hot water fixtures; pedestal fan; downlight covers.

**Retrofit Allocation Process:** a key challenge was the implementation of this major retrofit program across a large number of homes in a time- and budget-constrained project, whilst managing stakeholder expectations, including contractors and householders. In this project a unique process was developed to prioritise/select effective and household-specific retrofit packages for a number of 'batches' of homes.

**Consultation:** household 'consultation visits' ensured that participants remained at the centre of decisions even after the rigorous technical assessment and allocation process. Some householders rejected high-value, highly-recommended retrofits due to personal perceptions and so alternatives were worked through during the 'consultation visit'. Any agreed door draught seals, pipe lagging and LED light bulb replacements were generally installed by the project team at the end of this visit, avoiding additional visits and household disruption by tradespersons for relatively simple installs.

**Implementation:** Detailed 'work orders' were then developed for each retrofit on each home. The level of detail/quality of these work orders was crucial in the overall success of the project, since lack of attention to detail in the installation had the potential to very significantly compromise energy efficiency of the retrofits, (e.g. poor insulation detailing). This was also addressed by close engagement with contractors in an interactive, mandatory training/induction to stimulate their own thinking, knowledge and proactive practices.

#### 4. Energy and Thermal Comfort Monitoring

To enable quantitative evaluation of the impact on energy consumption and thermal comfort, authority was gained from participants to obtain electricity and gas billing data directly from energy distributors from two years before through to two years after the retrofits. ‘iButton’ temperature sensors at 0.5°C resolution were also installed in the main living area logging every half-hour. This cohort remained engaged in the longitudinal survey of knowledge, practices, attitudes/values conducted by the social marketing research team.

Each of the ~30 randomly chosen intensively-monitored homes had a comprehensive Jetlun™ energy and thermal comfort monitoring system of wirelessly networked sensors installed. Electrical energy consumption (real power) was logged every minute from switchboard circuits and ~5 major appliances in the home. Up to six air temperature and humidity sensors logged every 5 minutes, while reed-switches were used to monitor how people use windows and doors to ventilate their homes. Hot water flow and temperature were also logged. The system communicated through a ZigBee wireless network to the central data logger which used a 3G Router to email data every 24 hours to the research team. Blower door testing was also carried out on these homes to the ISO9972:2015 standard [9] using Retrotec™ equipment. Ethnography interviews and ‘video tours’ also added rich qualitative data to complement the technical dataset.

#### 5. Results and Discussion

A summary of some of the key statistics pertaining to the study group is shown in Fig. 3. The age of the dwellings showed a significant fraction being in the age group 20-29 years, with 61% of ILUs in this age range. The hot water system type is shown in Fig. 5b. The most common hot water system was the least efficient, i.e. electric storage, in 49% of the dwellings.

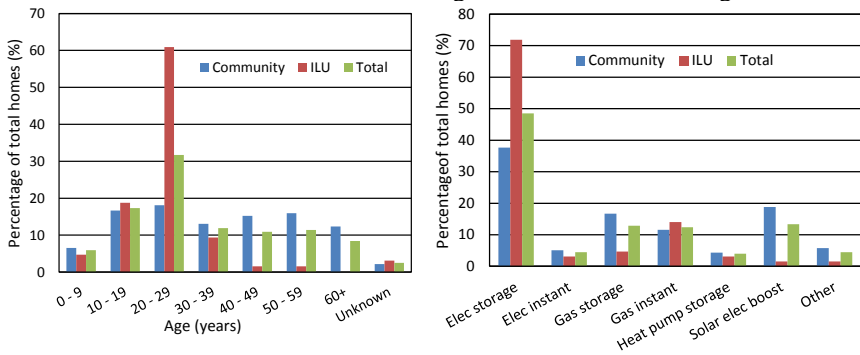


Fig. 3 House characteristics: a) dwelling age and b) hot water system type.



The information from the Building Characterization Tool provided insights into household practices from this particularly vulnerable sector of our society. Key issues included: occupancy patterns, showers/hot-water usage patterns, heating and cooling usages, and window usage.

Results on occupancy patterns showed that more than half of the households were occupied virtually all the time. Details on occupancy patterns showed that on weekdays approximately 20% of households were unoccupied for one to four hours, and 15% for five or more hours.

Cooling and heating practices were self-reported by the households during the Building Characterisation Audit in answer to the question ‘When do you typically use the heating in your living room/bedroom’. For this cohort of low-income elderly people it is clear that bedrooms are rarely heated as compared to living rooms.

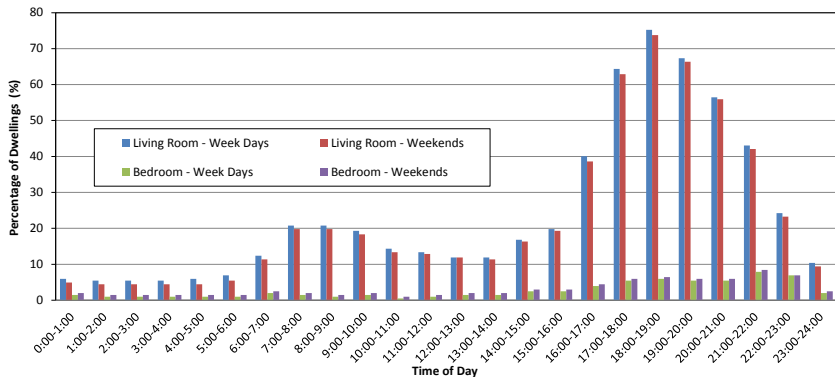


Fig. 4 Self-reported average use profiles for heating systems in winter.

Household reporting of natural ventilation practices (i.e. opening of windows showed that, in summer, 32% of the households kept the main living room windows always open, whilst in winter 46% kept windows always closed (Fig 5a). For bedrooms during winter 40% of all households reported that they kept the windows always closed, and 32% always open.

Due to a number of delays in the implementation of the project, and particularly in respect of acquisition of utility billing data, we are not able to provide comprehensive results for household energy consumption until later in 2016. However, our preliminary analysis of temperature monitoring data has revealed a number of interesting issues. Given the limited space available herein we focus on results from a particular case-study dwelling.

We consider the effect of installing ceiling insulation on the indoor temperature for the case study dwelling. Indoor temperature results are shown via the ‘temperature signature’ of the living room, where the half-hourly indoor air temperature data is plotted against the outdoor air temperature (Fig. 5). Such a scatter plot provides useful information both

visually and quantitatively on issues such as the thermal performance of the building, overheating hours, etc.

Indoor temperature data was downloaded from the iButton micro-temperature loggers and analysed for the period of 1<sup>st</sup> October 2015 to 11<sup>th</sup> January 2016, which included the time of the ceiling insulation retrofit on 4<sup>th</sup> December 2015 (it should be noted that this dwelling had air conditioning installed). The ambient dry bulb temperature was measured at the roof-top weather station installed at the UOW Sustainable Buildings Research Centre.

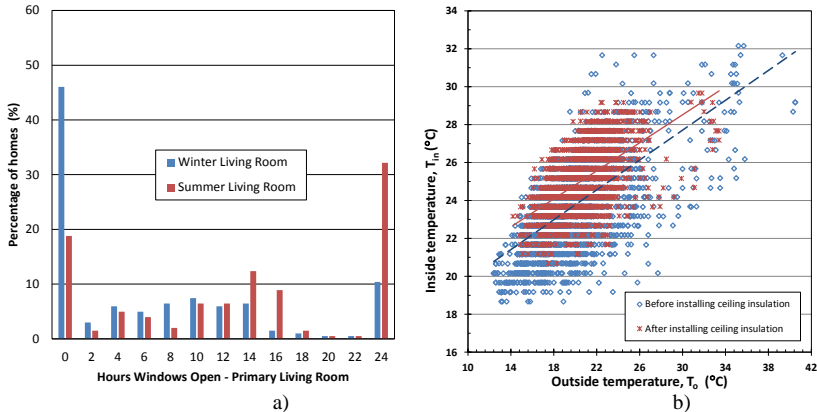


Fig. 5 a) Window opening practices from Building Characterisation audits: main living room; b) case study dwelling living room temperature, October 2015-January 2016, half-hourly data.

Indoor and outdoor temperatures were cross-correlated using MatLab to estimate the mean time lag between the diurnal outdoor and indoor air temperature signals; a result of the dwelling thermal mass. In this dwelling the time lag was found to be  $\sim 4.5$  hours. The temperature signature (without time lag incorporated) is shown in Fig. 5b prior and after insulation installed.

It can be seen (Fig. 5b) that the addition of ceiling insulation appears not to have changed the slope of the temperature signature significantly, but it did increase the indoor temperatures by  $\sim 1.0^\circ\text{C}$  on average during this summer period. Ceiling insulation was hoped to reduce inside summer temperatures, however, the mean temperature rise could be attributed to the fact that when the air conditioner was not in use heat from solar and internal gains could have been made harder to remove if the occupants did not control heat gains and ventilation appropriately. This outcome has been reported previously by other researchers, e.g. [6]. A potential solution could be through changes to occupant practices. The occupants reported closing the windows every day at 7pm and hence they would not benefit from the lower outdoor temperatures overnight to cool their homes. Social marketing materials including simple videos have been developed and distributed to help participants understand these principles. Air tightness measurements

were conducted in 7 dwellings to date (May 2015 to December 2015). Results showed that the average infiltration of the dataset was 21.7 ach, with a minimum of 7.5 ach and a maximum of 28.6 ach.

## **6. Conclusions**

This paper has outlined the approach taken to a significant residential energy efficiency retrofit program in the Greater Illawarra Region, Australia.

We have reported on the development of a unique Building Characterisation Audit Tool that was used to provide comprehensive data on the buildings to be retrofitted and the practices of the occupants, providing detailed information for the robust retrofit assessment and implementation process. Once the building/occupant database comprising tens of thousands of fields of data had been assembled a comprehensive assessment process was adopted to make recommendations to the overall project management team as to the best retrofits to install in each home, enabling effective, householder-centred improvements to be delivered in an efficient manner.

Indoor temperatures were measured in all homes to be retrofitted, and in each of a subset of nearly 30 homes, a wireless-enabled intensive monitoring system was installed to record appliance energy consumption, indoor thermal comfort, etc. The preliminary data from these systems has provided vital information that reinforces the importance of taking a multi-disciplinary and holistic approach to large-scale retrofit projects such as the present.

## **Acknowledgment**

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