A bottom-up data collection methodology for characterising the residential building stock in Australia

Clayton McDowell
University of Wollongong, cm639@uowmail.edu.au

Georgios Kokogiannakis
University of Wollongong, gkg@uow.edu.au

Paul Cooper
University of Wollongong, pcooper@uow.edu.au

Michael P. Tibbs
University of Wollongong, mtibbs@uow.edu.au

A bottom-up data collection methodology for characterising the residential building stock in Australia

Abstract

In Australia the majority of the current residential building stock has been constructed with little regard to energy consumption or thermal comfort. With only 1-2 % of Australia's building stock being replaced each year retrofitting solutions are necessary if residential energy consumption is to be reduced. Australia's records of the characteristics of its current building stock are minimal and outdated and thus these need to be renewed to enable the evaluation of retrofit upgrade strategies. Thus this paper presents a methodology and results of a bottom-up data collection tool that captured building and occupant characteristics from 200 elderly low income dwellings. The methodology was developed to include the consultations of local retrofit installers in which this process provided additional data fields around standard practices and retrofit requirements. By capturing these fields it was found that of the dwellings with suspended floors and no insulation only 52 % had clearance that would allow for an insulation retrofit. Without data fields such as these additional site visits would be required prior to confirming the suitability of a retrofit strategy. Over 90 % of the dwellings were found to be constructed prior to minimum energy efficiency standards and hot water systems were found to be an opportunity for energy savings with almost 50 % of the dwellings using electric storage hot water systems.

Keywords

characterising, australia, methodology, stock, building, collection, data, up, bottom, residential

Disciplines

Engineering | Science and Technology Studies

Publication Details

McDowell, C., Kokogiannakis, G., Cooper, P. & Tibbs, M. (2016). A bottom-up data collection methodology for characterising the residential building stock in Australia. CESB 2016 - Central Europe Towards Sustainable Building 2016: Innovations for Sustainable Future (pp. 221-228).

A BOTTOM-UP DATA COLLECTION METHODOLOGY FOR CHARACTERISING THE RESIDENTIAL BUILDING STOCK IN AUSTRALIA

Clayton McDowell[a], Georgios Kokogiannakis[a], Paul Cooper[a], Michael Tibbs[a]

[a] *Sustainable Buildings Research Centre (SBRC), Faculty of Engineering and Information Sciences, University of Wollongong , Wollongong, Australia, sbrc@uow.edu.au*

Abstract

In Australia the majority of the current residential building stock has been constructed with little regard to energy consumption or thermal comfort. With only 1-2% of Australia's building stock being replaced each year retrofitting solutions are necessary if residential energy consumption is to be reduced. Australia's records of the characteristics of its current building stock are minimal and outdated and thus these need to be renewed to enable the evaluation of retrofit upgrade strategies. Thus this paper presents a methodology and results of a bottom-up data collection tool that captured building and occupant characteristics from 200 elderly low income dwellings. The methodology was developed to include the consultations of local retrofit installers in which this process provided additional data fields around standard practices and retrofit requirements. By capturing these fields it was found that of the dwellings with suspended floors and no insulation only 52% had clearance that would allow for an insulation retrofit. Without data fields such as these additional site visits would be required prior to confirming the suitability of a retrofit strategy. Over 90% of the dwellings were found to be constructed prior to minimum energy efficiency standards and hot water systems were found to be an opportunity for energy savings with almost 50% of the dwellings using electric storage hot water systems.

Keywords: *building characterisation, bottom-up, retrofit, residential dwellings, residential building stock*

1 Introduction

The improvement of the energy efficiency of the residential building stock is prudent if we are to limit global warming to 2°C relative to the pre-industrial era. In 2013 the residential sector accounted for 10.4% of Australia's greenhouse gas emissions, equating to 57.1 Mt of CO_2 emissions, an increase of 41.1% since 1990 [1]. Although a large proportion of this can be attributed to residential transport, a total of 12.3 Mt of CO_2 emissions can be attributed to non-transport activities which was an increase of 44.3% from 1990 and 3.1% from 2012 [1]. If Australia is to reduce these emissions quantifiable records of the characteristics of the existing building stock is first required in order to evaluate the stock in terms of energy efficiency and potential energy conservation measures (ECM) or building retrofits.

In many countries building characteristic data is collected at regular intervals through census or energy consumption surveys, however in Australia there is an absence of up to date publically available data sources for building characteristics especially for an address level. For Australia the most comprehensive data source available is the Census of Population and Housing, however the last census to contain detailed building characteristics was conducted in 1986 [2]. Although the primary building characteristics for those buildings constructed prior to this 1986 census may not have changed greatly, the potential effectiveness of a retrofit may have because of design changes through renovations. This is shown through a study conducted in 2002 that found 58% of owner occupied dwellings in Australia had undergone renovations between 1989 and 1999, this excluded any maintenance or repairs undertaken [3]. Subsequently a following study was conducted that predicts residential energy use between 1986 to 2020, however this study relied on several smaller localised studies and assumed these conditions are applicable Australia wide [4]. It is therefore essential to develop systematic methods that could capture the special characteristics of Australian buildings and extrapolate them in a way that meaningful energy retrofit upgrade strategies could be evaluated. As an example, a special characteristic could be a skillion roof that is not common in other parts of the world and can be associated with prescribed insulation levels. Data collection methods should be able to capture such localised data and relationships.

Previous residential characteristic programs were first examined and evaluated for their methods used in the data collection process and the data fields collected. Firstly the Australian Building Sustainability Index (BASIX) [5], Home Power Savings Program [6] and Home Saver Rebates Program [7] were investigated. It was found that the data fields used in these programs were relevant and designed for an Australian context, however they did not contain data fields that enabled tailored retrofits to be recommended. As an example these programs did not collect details on available underfloor clearances for sub-floor insulation, available fridge cavity dimensions for fridge replacements or room volumes for heating or cooling replacements.

The United States Residential Energy Consumption Survey (RECS) was also investigated as it is undertaken every four years and provides a rich database, however the data fields are specific to the typical buildings found in the United States and the survey does not provide the level of detail required to assist retrofit installers [8].

Many other studies such as those reviewed by Fumo [9], Foucquier et.al. [10], and Boeck et. al. [11], demonstrate how building characteristics can be used to evaluate energy consumption and building retrofits, however these studies primarily rely on existing databases or fall short of detailing the data collection methodology [9]–[11]. Although various data collection and audit tools have been developed within other countries, these tools are difficult to apply to countries outside of their developed context. This is due to large variations in building construction types, construction materials and barriers to retrofits. These variations can be accounted to many aspects such as local climate, age of buildings, cultural differences and local policies. In addition to this, most existing retrofit decision tools target specific retrofits during an auditing process and their current reported methodologies do not consider the flexible approach of including information on multiple possible retrofits.

The purpose of this paper is to present the developments from the first phase of a low income residential energy efficiency improvement project. The first phase developed a new methodology for capturing building and occupant characteristics of residential dwellings with the aim of characterising the building stock, evaluating energy consumption and determining suitable building retrofits in an integrated way. The method of developing the data collection tool can be used to develop data fields specific to program outputs and local context. The bottom-up collection of building characteristics is challenging and costly and thus this research seeks to reduce future project costs of retrofitting by not only capturing data to evaluate energy consumption but also collecting information prudent to the installation process of retrofits. This additional data is a special characteristic of our proposed method since it enables the evaluation of the practicality of the retrofit install and allows information to be provided to the installers to enable a streamlined installation process.

This research was conducted as part of the Energy + Illawarra project which seeks to improve the energy efficiency of 800 elderly (aged 60 years or older), low income homes whilst maintaining or improving their thermal comfort. This was achieved through a multidisciplinary approach involving social marketers, human geographers and engineers. Within this a building characterisation and retrofit program was undertaken that targeted 200 dwellings. Of these dwellings 30 underwent intensive monitoring of their energy consumption and indoor temperatures and an additional 10 dwellings were selected as a control group that underwent the intensive monitoring and building characterisation but did not receive a building retrofit. The ultimate goal of this research project is to inform future evidence based policy into methods for improving energy efficiency and assisting elderly low income households in reducing energy costs whilst maintaining or improving their thermal comfort.

The research project was undertaken across the Greater Illawarra of New South Wales Australia. The Australian Building Codes Board (ABCB) classes this area under two climate zones, warm temperate and mild temperate [12]. The warm temperate dwellings located in Wollongong experience mean minimum winter temperatures of 8.3°C and mean maximum summer temperatures of 25.6°C but can experience temperatures as high as 44°C and as low as 1°C [13]. Other participant dwellings such as those located in Bowral are classed under the mild temperate climate zone and experience mean minimum winter temperatures of 2.1°C and mean maximum summer temperatures of 25.5°C but can experience temperatures below 0°C and up to 40° C[14]. Therefore these dwellings are neither dominated by either heating or cooling but require both in order to remain comfortable throughout the year.

This paper has been divided into 3 sections; the methodology explains the steps taken to develop the data collection tool for capturing relevant building characteristics, the results provide some preliminary findings about the buildings in this cohort, and the conclusion and recommendations summarise the findings of this paper and provide recommendations for future work.

2 Methodology

2.1 Data collection method

The methodology used for the development of the data collection tool is comprised of five major stages. The determination of required program outputs, literature review and expert consultation, collation of data fields, evaluation of data fields, and testing / application of the data collection tool. An iterative process was established to refine the tool and is illustrated in figure 1.

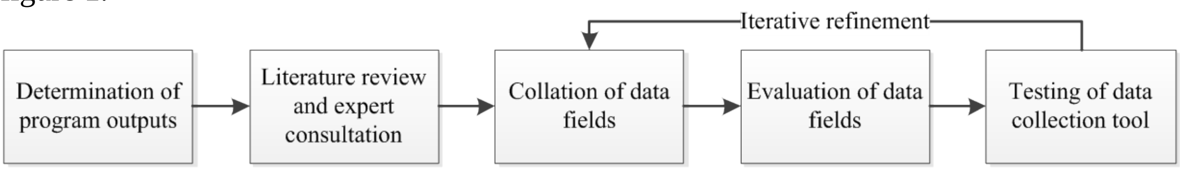

Fig. 1 *Data collection methodology*

The first stage of the methodology involved a detailed analysis of the expected program outputs. This stage is key as it defines what comes in the following stages and thus it is beneficial to understand the purpose of the data collection, what the data will be used for in the present, and what it may be used for in the future. Characterising the local residential building stock should enable us to develop a statistical energy consumption model, develop a series of building energy simulation models and determine suitable building retrofits for a sample of 200 dwellings. Stage 2 involved the generation of data fields by performing an analysis of each of the program outputs determined in stage 1, these analyses included literature reviews and consultations with local expertise.

A literature review was performed on previous statistical energy consumption models to understand the fields used in their statistical analyses. Similarly a review of building energy simulation programs such as AccuRate [15] and EnergyPlus [16] was undertaken to understand their inputs and experienced building energy modellers were consulted.

The final output of determining suitable retrofits was examined for both energy savings and practicality of installation. To assist with this, local architects, local retrofit installers and local training organizations were consulted. By consulting stakeholders that are involved with the practical side of the retrofits a series of critical data fields were able to be included into the data collection tool. These fields included questions surrounding adequate clearances such as for underfloor insulation, inspection for asbestos contained in electrical distribution boards which require replacement if additional circuits are added, etcetera. This enabled a streamlined installation process to take place as this reduces the need of sending installers to double check if a retrofit is practical to install.

Stage 3 collated all of the data fields that were generated from stage 2 into a single list of data fields. This list was then used in stage 4 in which each of the data fields underwent an evaluation for the level of intrusiveness, equipment required to collect the data, estimated time for collection and ranked on the priority of capturing the data. It was found that a careful balance between time to collect the data, quantity of data fields and precision of data collection had to be reached (Figure 2). This was not only to minimize the cost to capture the data but also to limit the burden that is placed on the participant, this is especially so when working with a vulnerable group of society such as elderly low income.

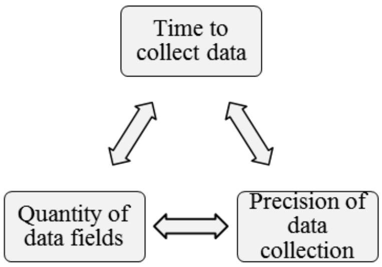

Fig. 2 *Data collection balance approach*

Stage 5 then collected the final list of data fields and programmed these into an html interface that enabled offline collection of the data. The data collection tool and list of data fields underwent a series of evaluations and iterations until the balance as described above was reached. To further illustrate the methodology undertaken in the creation of the data tool an expanded version of Fig.1 has been provided in Fig.3. Using this method, a locational specific data collection tool was created and was used to capture the characteristics of over 200 dwellings.

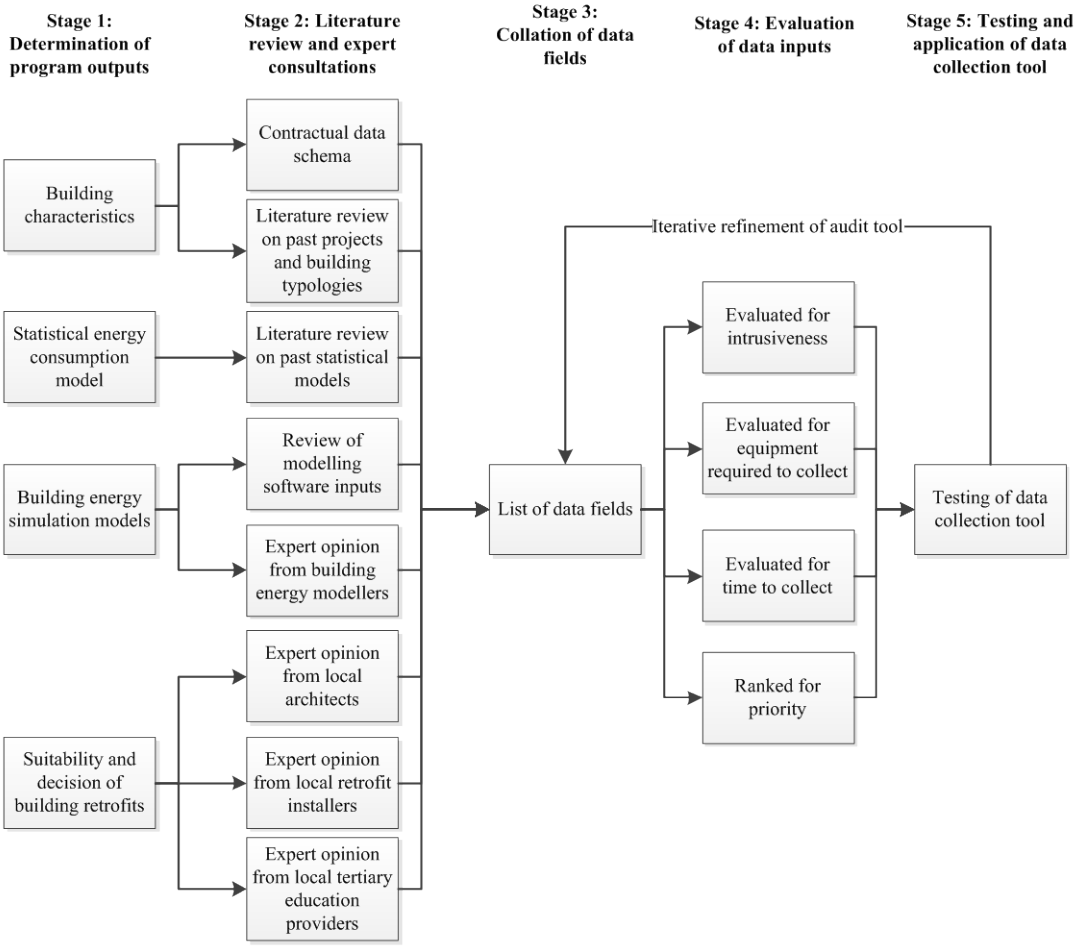

Fig. 3 *Expanded data collection methodology*

2.2 Participant selection and visits

Participants for this study were recruited from the general community, and independent living units (ILU) from within aged care facilities. The general community participants were randomly selected from the remaining participants to bring the total number of building characterisations to 210 in which 200 would receive a building retrofit and 10 to be monitored as part of a control group. The total number later reduced to 202 participants due to various circumstances such as sickness, holidays and intrusiveness resulting in 138 general community and 64 ILU participants.

After several trials, the building characterisation visits were restricted to be completed within two hours. This was established to reduce the burden placed on the participants and it was therefore essential to capture the required data in an as efficient way as possible. The building characterisation visits were booked via telephone calls and during this process several questions were asked to gauge the size and complexity of the dwelling. Dwellings considered complex were visited by two trained auditors whilst the remaining dwellings were visited by a single auditor. On average over 100 photographs were taken at each visit and included photographs of the building exterior, internal rooms, windows, appliances, lighting, and ventilation etcetera. These were used for post processing of any incomplete fields and to provide retrofit specific photographs to the installers to further enable a streamlined retrofit process.

3 Results

In 2005 BASIX [15] was introduced to the State of New South Wales in Australia as the first measure to improve energy and water efficiency of residential dwellings. This measure was only applicable to new dwellings and was not expanded to include major renovations until 2006. This expansion was placed on renovations of a value of $100,000 or more, and the value was later reduced to $50,000 in 2007 [15]. For the buildings of our study it was found that less than 6% of the dwellings were constructed post 2005 (Figure 4). Therefore the vast majority of dwellings in this cohort were constructed prior to the introduction of minimum energy efficiency requirement.

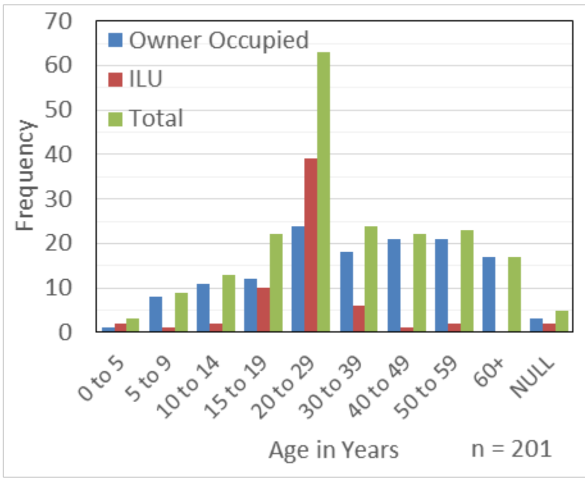

Fig. 4 *Dwelling age distribution*

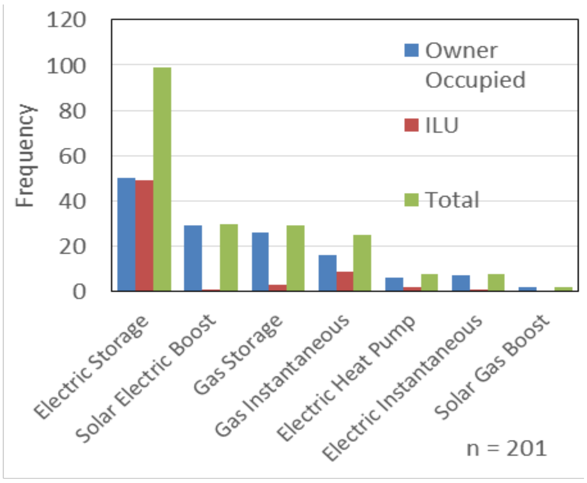

Fig. 5 *Dwelling hot water distribution*

The dwelling types were found to vary greatly between the community and ILU dwellings with 90% of the community dwellings classed as detached homes and less than 5% as semi-detached. In comparison less than 10% of the ILU dwellings were detached with the remainder being semi-detached or multi-level units.

Wall insulation was unable to be physically inspected within the prescribed timeframe of the audits and so participants were asked if they were aware of the presence of any wall insulation and if so the type of insulation. Of the community participants 15% believed that insulation was present and were able to name the type. In comparison, only 1.5% of the ILU participants were aware of insulation being present. Overall 43% of the participants believed that no wall insulation was present and 41.5% did not know if it was present or not. This shows the high degree of uncertainty associated with the current knowledge for the state of buildings in New South Wales. A small subset of dwellings underwent thermal graphic imaging but commonly the local environmental conditions on the day of the audit resulted in less than certain results.

Electric storage hot water systems were found to be the most dominant systems with 37% of the community and 75% of the ILU dwellings relying on electric storage (Figure 5). The majority of dwellings were also found to contain inadequate pipe lagging for their hot water systems.

Almost 5,000 lights were counted throughout the program with compact fluorescent (CFL) lights being the most prominent with a 39% share and fluorescent accounting for 18%. Incandescent and halogen lights still accounted for 24% and 14% respectively with LEDs only accounting for 5%. Occupants were also asked to estimate the number of lighting hours for the main living room and main bedroom for summer and winter and both weekdays and weekends. Such questions, in combination with questions about window opening patterns, heating/cooling system use and other activities in the house, were useful to determine the impact of retrofits on energy savings and indoor thermal comfort. The activity data were also collected as a requirement to derive occupant behaviour patterns while simulating the buildings with building simulation programs.

Sub-floor insulation was one of the retrofits considered as part of the program and to determine suitability the floor type, presence of insulation, floor access and joist width was captured. It was found that 49% of the community dwellings had suspended floors and over 89% of these did not have any sub-floor insulation, however of these dwellings only 57% were considered to have adequate sub-floor clearance to allow for installation.

Overall the data collection tool successfully captured many building and occupant characteristics including others not reported here such as the type of heating and cooling, external shading, appliances, and a series of occupancy questions around the use of natural ventilation, appliances and time of occupation.

4 Conclusion

This study developed a data collection methodology for the gathering of building and occupant characteristics in order to establish the basis for building characterisation, evaluating energy consumption and assessing the suitability and practicality of building energy retrofits for the dwellings in this project.

The majority of the dwellings in this study were found to be constructed prior to the introduction of energy efficiency standards which highlights the potential of retrofitting programs. Electric storage hot water systems were found to be the most prominent systems and energy savings could be found if these were replaced for more efficient systems such as solar hot water or heat pump systems.

The methodology used for the creation of the data collection tool included a consultation process with retrofit installers, through this process special characteristic fields such as sub-floor clearances were added. This addition highlighted that although the majority of community dwellings with suspended floors did not contain sub-floor insulation, only 57% had adequate clearance to enable a retrofit install. These data fields may be specific to the standard practices or regulations to the local area and thus it is recommended that this process be applied where variations may exist.

Additional changes to the tool could occur as more houses are audited, and in particular changes that capture the stochastic activities of occupants that belong to different demographics. These fields could then be integrated into the retrofit selection process and enable greater accuracy in the selection of retrofits that are suitable to the particular behaviour and preference of occupants.

Although this project was provided with a data schema as part of its funding, it would be highly beneficial for a standard data field list to be established for characterising the Australian residential building stock. This would enable further cross comparison analysis between projects and provide the possibility of building a representative database of Australia’s residential building stock.

Acknowledgement

We wish to thank all our EE3A consortium partners. This activity received funding from the Australian Government, Department of Industry and Science Low Income Energy Efficiency Program. The views expressed herein are not necessarily the views of the Commonwealth of Australia, and the Commonwealth does not accept responsibility for any information or advice contained herein.

References

[1] Australia's National Greenhouse Accounts, 2015. *National Inventory by Economic Sector 2013, Commonwealth of Australia 2015*.

[2] ABS, 1988. *2102.0 - Census of Population and Housing, 1986.*

[3] ABS, 2002. 4102.0 - *Australian Social Trends, 2002*.

[4] Energy Efficient Strategies, 2008. *Energy Use in the Australian Residential Sector 1986 - 2020*, Canberra: Department of the Environment, Water, Heritage and the Arts.

[5] BASIX, 2013. *BASIX for single dwelling Data input checklist*, pp.1–8.

[6] NSW Office of Environment and Heritage, 2015a. *Home Power Savings Program* [online]. NSW Office of Environment and Heritage. [cit. 2015-12-01]. WWW: <http://www.environment.nsw.gov.au/energyefficiencyindustry/home-power-savings-data.htm>.

[7] NSW Office of Environment and Heritage, 2015b. *Home Saver Rebates Program* [online]. NSW Office of Environment and Heritage. [cit. 2015-12-01]. WWW: <http://www.environment.nsw.gov.au/energyefficiencyindustry/home-data-rebates.htm>.

[8] U.S. Department of Energy, *EnergyPlus* [online]. [cit. 2015-12-03]. WWW: <https://energyplus.net/>.

[9] Fumo, N., 2014. *A review on the basics of building energy estimation*. Renewable and Sustainable Energy Reviews, 31, pp.53–60.

[10] Foucquier, A. et al., 2013. *State of the art in building modelling and energy performances prediction: A review*. Renewable and Sustainable Energy Reviews, 23, pp.272–288.

[11] De Boeck, L. et al., 2015. *Improving the energy performance of residential buildings: A literature review*. Renewable and Sustainable Energy Reviews, 52, pp.960–975.

[12] Australian Building Codes Board, 2012. *ABCB NSW and ACT Climate Zone Map.*

[13] Bureau of Meteorology, 2015a. *Climate statistics for Australian locations: Wollongong* [online]. Climate statistics for Australian locations. [cit. 2015-12-03]. WWW: <http://www.bom.gov.au/climate/averages/tables/cw_068188.shtml>.

[14] Bureau of Meteorology, 2015b. *Climate statistics for Australian locations: Bowral* [online]. Climate statistics for Australian locations. [cit. 2015-12-03]. WWW: <http://www.bom.gov.au/climate/averages/tables/cw_068102.shtml>.

[15] NSW Planning and Environment, 2015. *BASIX - Building Sustainability Index* [online]. [cit. 2015-11-18].
WWW: <https://www.basix.nsw.gov.au/basixcms/>.