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Design a Zero Energy House in Brisbane, Australia

Yuanming Kwan, Lisa Guan[a,]*

[a]*Queensland University of Technology (QUT), GPO Box 2434, Brisbane, QLD 4001, Australia*

Abstract

Due to the increasing energy demand and global warming effects, energy efficient buildings have become increasingly important in the modern construction industry. This research is conducted to evaluate the energy performance, financial feasibility and potential energy savings of zero energy houses. Through the use of building computer simulation technique, a 5 stars energy rated house was modelled and validated by comparing the energy performance of a base case scenario to a typical house in Brisbane. By integrating energy reduction strategies and utilizing onsite renewable energy such as solar energy, zero energy performance is achieved. It is found that approximately 66 % energy savings can be achieved in the household annual energy usage by focusing on maximizing the thermal performance of building envelope, minimizing the energy requirements and incorporating solar energy technologies.

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Keywords: Zero energy house; Subtropical climate; Financial feasibility; Building simulation

1. Introduction

Green building has attracted significant attention recently due to the rapid increase in energy consumption around the world, exhaustion of energy resources and environmental concern such as global warming. The global energy consumption is expected to increase by 56% between 2010 and 2040 [1]. Building energy load is one of the major contributions to the increasing energy consumptions and global warming. Researches have shown that the global

* Corresponding author. Tel.: +61-7-3138 2484; fax: +61-7-3138 1516.
E-mail address: l.guan@qut.edu.au

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energy consumption by the residential sector accounts for approximately 18 % of the total energy usage and is expected to increase by 1.5 % annually [2].

To address this issue, the Australian Sustainable Built Environment Council's (ASBEC) Zero Emissions Residential Task Group has appointed a team led by the Residential Development Council (RDC) to work on the target of achieving zero energy performance and zero carbon for new and existing homes by 2020. In addition, the Building Code of Australia has introduced several important changes in 2010, requiring all new homes to achieve a minimum of 6 star energy rating under the Nationwide House Energy Rating Scheme [3].

Zero energy house are typically houses with net zero energy consumption on a yearly basis, which means that the annual energy consumption is equal to the amount of renewable energy produced on site. The design of a zero energy house is basically reducing the energy consumed and meeting the demand on an annual basis by a renewable energy supply [4]. In the event where no renewable energy is available, electricity will be supplied to the house by the power grid. Power will be exported back to the grid when there is excess power generated by the renewable energy supply [5].

Although zero energy house can be built by the currently available technologies, the cost and repayment time often make it unattractive to many customers. This research project will focus on designing an affordable zero energy house based on a typical house in Brisbane, Queensland. Through the computer simulation, the energy performance of the house is investigated under Brisbane climate conditions. It is believed that the results obtained from the simulation will provide useful information on the possible energy savings of the different techniques. In addition, the result can also provide a guideline for the building industry. If the concept of zero energy house can be implemented throughout the whole Queensland, not only the energy consumption and greenhouse gas emissions will drastically decrease, but the annual household energy cost of Queensland residents will also reduce significantly.

2. Methods

This research was performed by using a building simulation software, which was used to simulate the building's performance based on the building model and climatic input data. Included in this section are the weather data for study location, building simulation tool, base case modelling and base case validation. The analysis of the energy reduction methods and the implication of solar energy will be discussed in the next section along with the results of the analysis.

2.1. Site location and weather data

Brisbane is the state capital of the Queensland, Australia. Its latitude is 27°23'S, the longitude is 153°07'E and the elevation is 4m. Brisbane has a humid subtropical climate with hot, humid summers and dry, mild winters. The summer (December – February) average temperature is 20-28°C, while the winter (June – August) average temperature is 11-21°C [6]. As the case study is located in Brisbane, the climate conditions of this research will be based on the Typical Meteorological Year weather profile dataset for Brisbane that can be downloaded from the U.S. Department of Energy website.

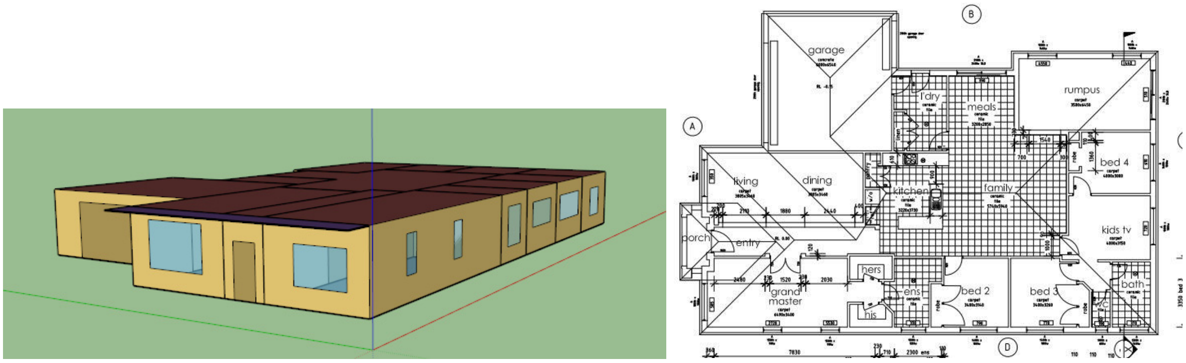
2.2. Building simulation tool

The EnergyPlus 8.1 building simulation software was applied to simulate the house energy performance in this paper. EnergyPlus is a building performance simulation program developed by U.S. Department of Energy. It integrates the existing features of BLAST and DOE-2 along with some additional new features [7].

EnergyPlus can model heating, cooling, lighting, ventilation and other energy flows. Some of the key capabilities include the ability to simulate time-step less than an hour, modular systems, heat balance-based zone simulation, daylighting control, thermal comfort and photovoltaic systems [8]. Therefore, EnergyPlus is an ideal software to model the energy performance of the zero energy house.

2.3. Basecase house modelling

A 5-stars energy rated modern single-storey brick veneer house was developed as the base case house for the study. This house was selected among 200 house plans submitted for building approval in Australia and is one of the eight sample houses used for energy rating software accreditation by Australian Building Codes Board [9].



(a) (b)

Fig. 1. A typical modern four bedroom house in Australia (a) floor plan [9] and (b) geometry of basecase house model.

Table 1. Construction specifications of the base house model.

Construction Type	Materials
External walls	100 mm brick, 50 mm insulation board (R1.5), wall air space and 9.5 mm plaster board.
External walls (garage)	100 mm brick, wall air space and 9.5 mm plaster board.
Internal walls	Double layer 9.5 mm plaster board and wall air space.
External door (front)	50 mm wood.
External door (garage)	50 mm steel (metal).
External door (laundry)	50 mm softwood.
Internal doors	25 mm wood
Windows	3 mm green glass (single glaze), air 13 mm and 3 mm clear glass.
Floor (carpet)	Carpet and 100 mm lightweight concrete.
Floor (tiles)	Acoustic tile and 100 mm lightweight concrete. (R1.0)
Ceiling	100 mm concrete, ceiling air space, 154 mm batts insulation (R3.5) and 13 mm plasterboard.

Figure 1 (a) shows the floor plan of the house. The house has a total built up area of 272.75 m2 and a net air-conditioned floor area of 191.76 m2. Included in the house are four bedrooms, a living room, two bathrooms, a rumpus room, a garage, a kids TV room, a kitchen/family area, an entrance walkway and a laundry. The basecase house model was modelled using Google SketchUp according to the floor plan. Figure 1 (b) shows the geometry of the basecase house model. By using EnergyPlus, the construction specifications of the basecase house are defined. This is tabulated in Table 1 based on the standards in line with the Australian Building Codes Board to represent a 5 stars energy rated house [10].

To model the internal loads, the lighting levels were modelled according to the BCA Lighting Benchmarks [11]. The lighting density of 2.77 W/m² was chosen for the indoors rooms, including bedrooms, bathrooms, kitchen, family rooms and living areas. Based on the BCA Residential Lighting Control [12], the lighting density for the garage was assumed to be 1.9 W/m². The light density for the entrance walkway was modelled slightly higher (i.e. 3.0 W/m²) as it was assumed that brighter lights are used at the entrance walkway. Based on the Protocol for House

Energy Rating Software [13], the maximum internal heat gain from the occupants and the general appliances at various zones were modelled and the schedules for internal loads, including occupancy, lighting and equipment were also defined. Table 2 shows the design level of the equipment in the specified zones.

Table 2. Design level of the general appliances of the base model.

Zones	Possible Equipment	Equipment Level (W)
Bathrooms	Hair dryer, shaver, etc.	1000
Kitchen / Family	Cooking stove, refrigerator, microwave, etc.	1100
Living Areas	TV, radio, laptop, etc.	300
Laundry	Washing machine	400

A unitary heat pump was modelled to represent the air conditioning system of a typical home. This was based on the research conducted by Cisro, which showed that most residential home in Brisbane uses heat pump air conditioning system [14]. The heating set point of the house was set at 21°C, whereas the cooling set point was 25.5°C. The COP of heating and cooling were set at 4.0 and 3.3 respectively. These settings were selected from the Protocol for House Energy Rating Software [13].

Based on a research conducted in 2005, gas water heaters covered 46 % of the Australian households [15]. Therefore, a gas storage hot water heating system with a tank volume of 0.4 m3 and a maximum heater capacity of 2200 W was modelled for the base case house. The hot water usage schedule used in this case study was based on the average Brisbane residential hot water demand pattern [16]. After defining all the input parameters, the energy performance of the base case house was simulated and the results were validated in the next section.

2.4. Validation of base case house model

Several mechanisms were used to validate base case house model. Firstly, the annual heating and cooling load per conditioned floor area of 56.25 MJ/m² as obtained from the simulation was found to agree well with the benchmark of heating and cooling load for a 5 stars house (i.e. 55MJ/m²) adopted by Nationwide House Energy Rating Scheme (NatHERS), with a difference of only 2.27 %. Secondly, the zones temperature during the air conditioned hours were analyzed and found to be maintained within the thermal set point temperatures of 21°C and 25.5°C. This indicated that the heating and cooling load are met by the air conditioning system, and the heating and cooling energy consumption are reasonably accurate. Thirdly, the energy breakdown data from the simulation was compared to a typical household in Queensland and both data only varies between 1 % and 2 % [17]. Finally, the seasonal change of the house energy consumption throughout a year was found to be in line with the relationship between outdoor air temperature and energy load.

3. Results and discussions

3.1. The performance of base case house

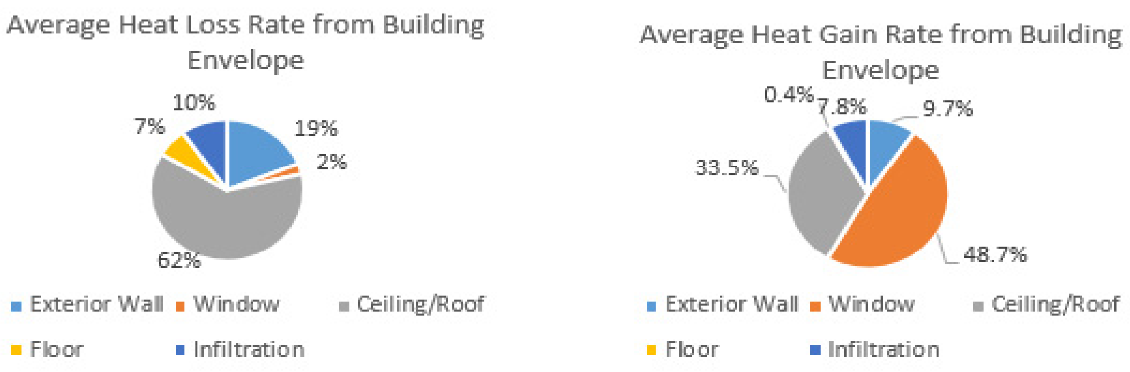


Fig. 2. Average heat loss and heat gain from building envelope.

The average heat gain and heat loss through the building envelope is illustrated in Fig. 2. It can be seen that the ceiling accounts for 36.3 % of the building envelope heat gain and 69.0 % of the building envelope heat loss. The design of windows is also important as it contributes 52.8 % of heat gains, but only 3 % of heat loss through building envelope. In contrast, floors only take 0.4 % of heat gain but 7 % of heat loss through building envelope. The heat gain and heat loss through exterior walls are 10.5 % and 21.0 % respectively.

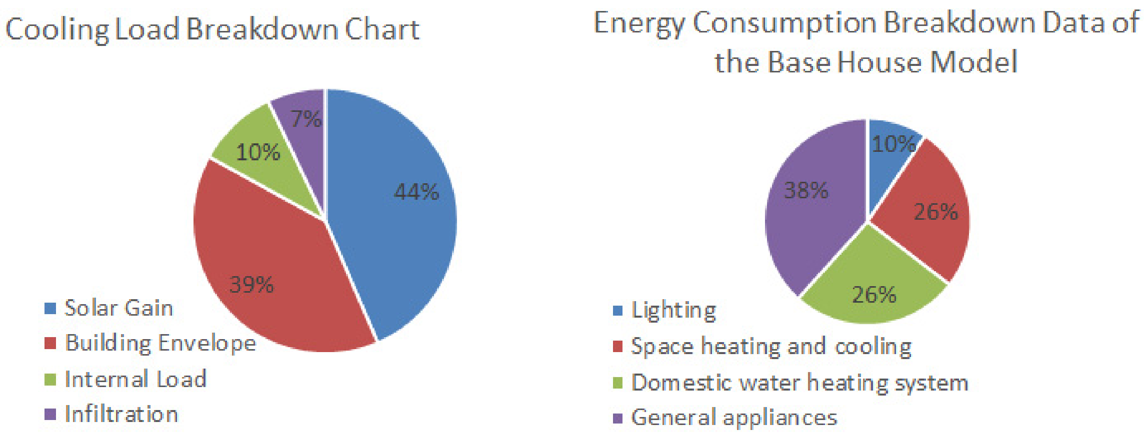


Fig. 3. Breakdown chart for building cooling load and annual energy consumption.

The heating load of the house is largely due to the conductive heat loss through the building envelope, assuming that the house is pressurised during conditioned hours. In addition to the conduction heat transfer, the cooling load is influenced by internal load and solar gain. This is shown in Figure 3(a). The results indicate that the solar gain contributes most significantly to the cooling load (47 %), followed by the building envelope (41 %) and internal load (12 %). The percentage of end-use energy consumption for the basecase house is further shown in Figure 3 (b). It can be seen that the energy consumptions are ranked in the order of general appliances, space heating and cooling, domestic hot water and lighting. These observations were also used as a guideline to develop options to reduce heating and cooling load.

3.2. The performance of modified house

To identify potential strategies to reduce house energy consumption, sensitivity analysis was conducted for various aspects, including building construction, energy efficiency of lighting and appliances, alternative hot water system and HVAC system. The following results were found:

- Optimum design of building envelope. Through increasing insulation for external walls and ceiling, adoption of white reflective roof, tinted reflective window glaze and exterior window shading, the HVAC system energy usage can be reduced by 66%.
- Energy efficient lighting and appliances. It is found that if lighting density is assumed to be 1.2 W/m² [12], the lighting energy can be reduced by 60 %. In parallel, if energy rating of appliances is increased by 2 stars (except for Television being increased by 4 stars) [18], the energy used by general appliances can be reduced by 42 %. The uses of higher efficiency equipment have also reduced the internal sensible heat load and led to 7.5 % decrease in the HVAC energy used.
- Adoption of solar energy technologies. Through the adoption of solar hot water collectors, which incorporate a three-in-one technology and provide hot water, cooling and heating, energy consumption by the domestic hot water and HVAC system can be reduced by 78.3 % and 80 % respectively.

The overall simulation results show that an overall energy reduction of 66 % can be achieved by integrating the above potential modifications. The modified house can achieve approximately 93 % decrease in the HVAC system energy consumption, from 56.26 MJ/m2 to just 3.75 MJ/m2 by improving the house construction, increasing existing lighting and equipment efficiency and introducing a solar absorption cooling system. The modified house can achieve a better energy performance than a NatHERS 10 stars rated house which consumes 10 MJ/m2 [13]. The annual energy used by the HVAC system is made up of 0.26 GJ of heating energy and 0.47 GJ of cooling energy. Table 3 shows the comparison of the energy usage of the base house model and the modified house. The modified house has a total energy consumption of 3.97 MWh per annum.

Table 3: Energy consumption of the base house model and the modified house.

Scenario	Energy Use Per Conditioned Floor Area				
	HVAC (MJ/m^2)	Lighting Energy (MJ/m^2)	Water Heating (MJ/m^2)	Equipment Energy (MJ/m^2)	Total energy (MJ/m^2)
Base House Model	56.26	20.43	56.86	82.94	216.49
Modified house	3.75	9.47	12.30	47.94	73.46

3.3. Adoption of renewable energy to achieve annual zero energy performance

Brisbane receives a daily average of 4.2 hours peak sun, making solar energy an excellent way to achieve energy balance [19]. A 5kW crystalline silicone photovoltaic panel system is modelled facing north at a tilted angle of 26 ° to compensate for the house annual energy demand. The average daily energy generated by the PV system is 19.5 kWh, leading to 7.2 MWh per year, which is greater than the household energy demand of 3.97 MWh per an-num. To show that the zero energy performance is met each month, the daily power generated by the PV system is compared to the daily energy requirement to confirm the applicability of the PV system. Figure4 shows the zero energy balance every month over the twelve months simulated period. The results showed that the house can achieve zero energy performance by generating more energy than the energy consumed every month. In addition to that, the excess powers that are generated by the PV system can be exported back to the power grid. Thus, the house has exceeded the minimum criteria of a zero energy house.

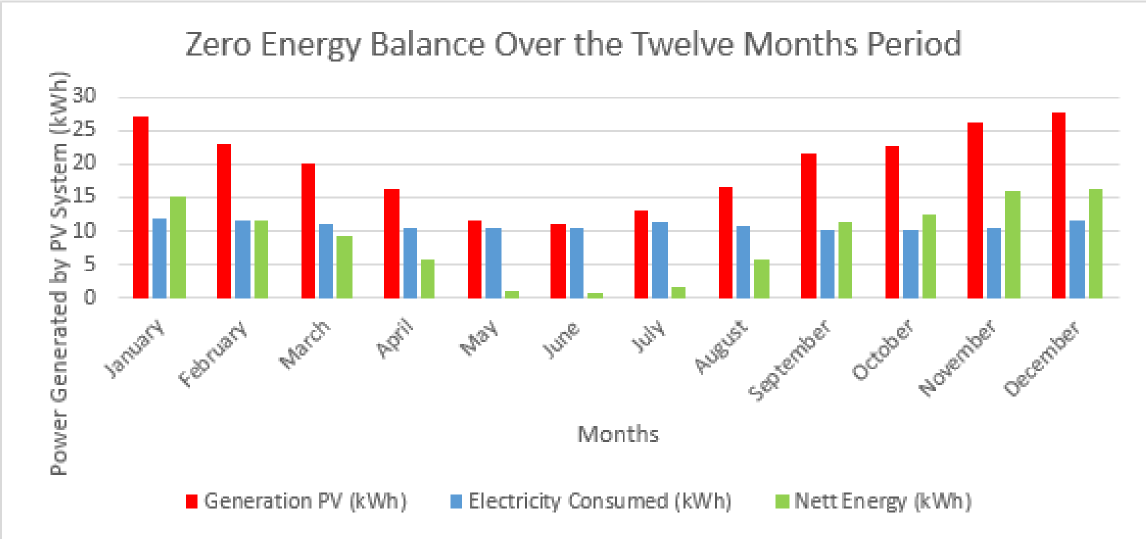


Fig. 4. Zero energy balance each month.

3.4. Financial feasibility

Based on the Rawlinsons Construction Cost Guide and other supplier's website, the additional building and equipment cost required to build the zero energy house sums up to AU$ 42090. However, the capital cost can be reduced by AU$ 4982 after taking account of the Small Technologies Certificate (STC) incentives offered by the Australian Government to promote Solar Technology. As a result, the additional capital cost is reduced to AU$37100, which is approximately 8.9 % of the average construction cost for a brick veneer house in Brisbane of AU$ 418000 [20]. Considering the electricity tariffs for 2015 being 27.916 (c/kWh including GST), the annual energy savings of 11.4 MWh by the zero energy house can result in a total savings of AU$ 3182 in the utility bill [21]. In addition, based on the Feed in Tariff of 10 c/kWh provided by the energy provider in Queensland, the excess energy of 3.23 MWh exported back to the power grid will generate an income of AU$ 323 [22]. Both of these lead to an annual cost benefit of AU$ 3505 and are expected to increase with the increasing energy price. Overall, the payback period of the zero energy house is estimated to be approximately 10 years. However, this may reduce with time as 10% increase in the energy price will shorten the repayment period by 10 %. Finally, it is found that energy efficient homes tend to have higher resale value due to higher demand and this trend is likely to increase [23].

4. Conclusions

The energy performance and financial feasibility of a zero energy house in Brisbane has been studied. Through building computer simulations, the potential energy savings through building modifications and energy efficient equipment as well as the applicability of solar energy have been investigated. The financial feasibility of the zero energy house have also been evaluated by estimating the additional cost and the payback period. Overall, it has been found that the zero energy house would require an additional 8.9 % of the construction cost and the payback period is approximately 10 years. Although this may seem to be a long period of time, the payback period is expected to decrease, because of the expected increasing in energy price and cheaper solar technologies. In conclusion, the zero energy house has been demonstrated to be feasible and an attractive option in Brisbane. More research will need to be conducted to investigate the performance of zero energy houses in other cities and states in Australia.

References

[1] U.S. Energy Information Administration. 2013. International Energy Outlook: With projections to 2040. Washington, DC: U.S. Energy Information Administration.
[2] L. Pérez–Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energy and Buildings. 40 (2007) 394–398.
[3] C. Riedy, A. Lederwasch, S. Harris, Net Zero Emission Homes: An Examination of Leading Practice and Pathways Forward, Sydney: Australian Sustainable Built Environment Council, 2012.
[4] L. Wang, J. Gwilliams, P. Jones, Case study of zero energy house design in UK, Energy and Buildings. 41 (2009) 1215–1222.
[5] P. Norton, C. Christensen, E. Hancook, G. Barker, and P. Reeves.. The NREL/Habitat for Humanity Zero Energy Home: A Cold Climate Case Study for Affordable Zero Energy Homes. Battelle: National Renewable Energy Laboratory, 2008.
[6] L. Guan, M. John, Monitoring energy performance of air conditioners in classrooms. In Teng, J.G. (Ed.) Proceedings of the First International Conference on Sustainable Urbanization ISCU 2010, The Hong Kong Polytechnic University, Faculty of Construction and Land Use, China, Hong Kong, 2010, pp. 1915–1924.
[7] C.B. Drury, L. Lawrie, C. Pedersen, F. Winkelmann, EnergyPlus: Energy Simulation Program, ASHRAE. (2000) 49–56.
[8] U.S. Department of Energy. EnergyPlus Energy Simulation Software. http://apps1.eere.energy.gov/buildings/energyplus/.
[9] Constructive Concepts. 2009. Building Improvements to Riase House Energy Ratings from 5.0 Stars. Australian Building Codes Board.
[10] X. Wang, D. Chen, Z. Ren, Assesment of climate change impact on residential building heating and cooling energy requirement in Australia, Building and Environment, 45 (2010) 1663–1682.
[11] Green Building Council Australia, Green Star Multi–Unit Residential Energy Calculator Benchmarking Methodology, Green Building Council Australia, 2009.
[12] Building Code of Australia. 2009. Residential Lighting Control.
[13] Australian Building Codes Board. 2006. Protocol for House Energy Rating Software.
[14] A. Michael, M. James, A. Law, P. Osman, S. White. The Evaluation of the 5–Star Energy Efficiency Standard for Residential Buildings. Canberra: Department of Industry, 2013.
[15] Department of the Environment, Water, Heritage and the Arts. Energy Use in the Australian Residential Sector 1986–2020. Canberra: Department of the Environment, Water, Heritage and the Arts, 2008.
[16] A.S. Vieira, C.D. Beal, R.A. Stewart, Residential water heaters in Brisbane, Australia: thinking beyond technology selection to enhance energy efficiency and level of service, Energy & Buildings. (2014) 222–236.
[17] YourPowerQld, Understanding Your Energy Use. https://www.yourpowerqld.com.au/start–saving/understanding–your–energy–use.
[18] State Government Victoria, Victorian Households Energy Report. Melbourne, Sustainability Victoria, 2014.
[19] M. James. 2012. Solar Power Brisbane. Solar Choice. 6 February. Accessed 21 April, 2015. http://www.solarchoice.net.au/blog/solar–power–brisbane–solar–choice–brisbane–office/.
[20] Rawlinsons. 2013. Rawlinsons Construction Cost Guide. Perth, Rawlinsons Publishing.
[21] Queensland Government Department of Energy and Water Supply. 2014. Current Electricity Prices. Queensland Government. Accessed 5 May, 2015. https://www.dews.qld.gov.au/energy–water–home/electricity/prices/current–prices.
[22] https://www.solarmarket.com.au/learn/tariffs/queensland/.
[23] Queensland Government Department of Housing, Smart Housing, Brisbane, Queensland Department of Housing, 2014.