BDP ENVIRONMENT DESIGN GUIDE

Filter House, Broome, Western Australia

Chris Jensen and Nicki Taylor

The Filter House design was developed as an entry to the Broome Sustainable Housing Competition, organised by the Western Australian Department of Housing and Works. The competition called for the design of a single dwelling on a greenfield site in Broome to meet the standard spatial and briefing requirements of the Department of Housing and Works but with significantly less impact on the environment. This paper briefly describes the building and investigates its post occupancy performance following twelve months of continual data collection.

1.0 Project Description

Client
Western Australian Department of Housing and Works

Architect and Project Management
Sustainable Built Environments

Structural Engineering
Tom Vinnicombe, Kimberley Structural

Services Engineer
Sustainable Built Environments

2.0 Introduction

The Filter House proposed a building system with the ability to help shift the provision of housing in north-west Australia onto a more sustainable footing – a lighter footprint. Providing quality housing within a government department budget, the design is appropriate for subtropical and tropical coastal climates throughout northern Australia.

This study aims to review the design of the Filter House as a successful design strategy for northern tropical Australia. The methodology is to review the metering and monitoring that has been undertaken for this dwelling and a similar sized Department of Housing and Works reference house over twelve months of occupancy and with similar occupant behaviour. This post-occupancy review process is critically important in evaluating the validity of any claims that the building is resource efficient.

3.0 Design Response

3.1 Urban Context

The design responds to the vernacular housing styles of both Broome and the wider region. It is raised off the ground, has an 18 degree roof pitch, corrugated iron cladding, large overhanging eaves, entry deck and deep shade created by the carport (Figure 1).

3.2 Climatic Response

The climate is coastal tropical with cooling sea breezes and blustery easterly winds. The average humidity is 60%. Figure 2 shows the temperature ranges throughout the year. The Building Code of Australia climate zone for Broome is Zone 1.

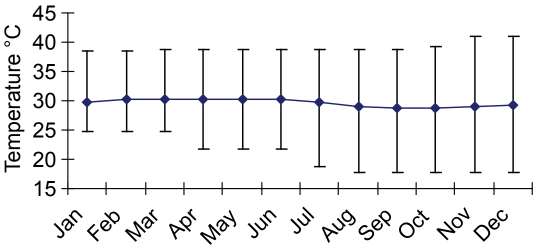

Figure 2. Measured Average, Maximum and Minimum Temperatures at the Broome 'Filter House'

Figure 1. Broome 'Filter House'

Figure 3. View of House from the North-West as Modelled (left) and Built (right)

4.0 Building Design

4.1 Passive Solar Design

Passive solar design was constantly reviewed throughout the design process, and addressed thermal performance, quality of light, filtered light penetration into rooms and the overall spatial volumes of the living areas.

In the context of Broome's tropical climate, a design priority for cooling performance often took precedence over winter solar gains. This cooling priority led to the development of a low thermal mass building fabric, designed to shed heat quickly. While the site places constraints on optimal building orientation, the design prioritises living areas and the main bedroom be placed on the north in order to benefit from some passive solar heating in cooler months, but focuses on the ease of shading in summer. The outdoor living areas are oriented to the north-west. Full rain and shade cover is provided to the deck by an insulated roof. To avoid this deep roof cover cutting off solar access to the living room, filtered northern light is made available by north facing clerestory windows above.

Passive ventilation has been extensively used in the cooling strategy for the proposal. Passive ventilation paths (chimneys) are set up by the high-set vented clerestory windows in both pavilions. They allow hot air to be vented from the top of the internal skillion volume, while air intakes can be moderated by opening lower set windows on the shaded orientations. Micro-climatic air pre-treatment can be provided from planting zones adjacent to the south facing street facade. Fully operable louvre windows have been positioned to maximise direct cross ventilation control from the full range of prevailing wind directions. Figure 3 shows the extensive shading and cross ventilation elements used in the building.

4.2 Air Conditioning and Heating

Air conditioning and heating represent about 26% of household energy use. To meet the competition brief requirement of maintaining internal temperatures between 17-27 ºC, active air conditioning is required. To achieve this economically, two 'cool cells' in the living and bedroom pavilions are well sealed and heavily insulated to an R-3.0 rating, including the sub-floor. These 'cool cells' create two thermally stable zones that can be effectively cooled or heated (Figure 4).

Minimisation of a split-system air conditioning unit is achieved by sizing the system to cool or heat one cell at a time, while enabling it to switch between living and bedroom cells by automatically timed control or active occupant switching. This 'cool cell' approach is calculated to provide at least a 50% reduction in the air conditioning system requirements for the house. The sliding door between the entry area and kitchen creates an air-lock to the 'cool cell'. External shading and screens reduce internal heat load.

Reverse-cycle units satisfy both heating and cooling requirements and negate the need and cost of a separate heating system for this relatively mild winter climate.

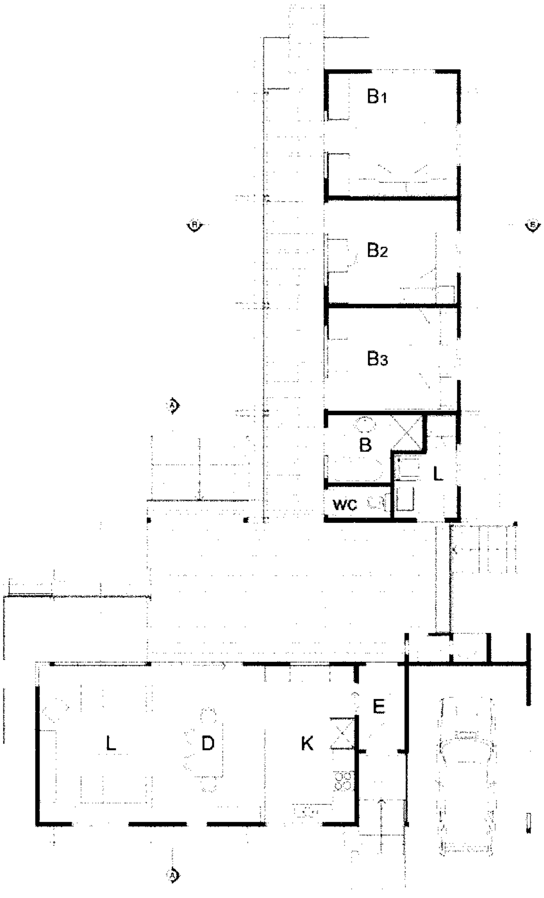

Figure 4. Floor Plan of the Filter House

Discussions and preliminary system requirements for the R-3.0 insulated, dual-zone 'cool cells' were held with a major domestic system manufacturer. Schematic sizing indicates a domestic split-system half the size of a standard system for a 150m² house would be able to maintain an internal temperature of 25 °C and be switched between the living and bedroom cells.

Standard single glazing with a thermal resistance of R-0.16 has been specified to stay within budget limitations. Solar calculations informed the design of the northern eaves and shade battens minimise glazing heat gains.

4.3 Gas

Gas use represents about 12% of household energy use. It should be noted that gas produces approximately one third of greenhouse gases compared to the equivalent electricity generation. For this project, gas has been used for as many applications as possible, such as the stove cook top and oven. It is also used to boost the solar hot water system.

4.4 On-Site Electrical Production from Photovoltaic System

Eleven photovoltaic solar panels are mounted on the northern facade of the building and are linked to the electricity grid connected inverter, maintaining grid availability, whilst also feeding excess supply back to grid. The regulator, inverter and reversing electronic meter are located in a ventilated meter cupboard to the east of the deck.

4.5 Electric Load Reduction

Low energy light fittings and energy efficient appliances have been specified throughout. Clothes-drying is achieved under the partially covered clothes drying area, in lieu of an electric clothes drier.

4.6 Solar Hot Water

Hot water uses approximately 31% of household energy. To reduce this level, 3.5m² of solar hot water collectors are mounted on the north facade at the eastern end of the living pavilion. They are mounted at 18 degrees which is the latitude of Broome thus giving optimal performance. Storage of this water is in a cupboard below, and gas boosting is provided to supplement the power as required. An automatic controller – with a manual override to turn the booster on in periods of low solar radiation – is provided in the meter cupboard.

4.7 Water Supply

The major response to reducing water usage is the provision of three 23,700L tanks to catch rainwater for non-potable water demands. This approach targets high volume water uses that do not have public health implications. Polyethylene tanks are cost-effective, have a long life cycle and require little maintenance. As tank water is only used in non-potable applications with mains supply as backup, this approach provides a low risk on-site system that achieves significant savings in water use.

Potable water use has been minimised by the use of 'AAA' rated fittings, with aerators used in all tapware. Due to issues relating to public health and the ongoing active management requirements, greywater and blackwater systems were not included.

5.0 Reference House

The Department of Housing and Works chose a reference house in Broome which could be monitored for energy consumption to compare the performance of the Filter House. The reference house was chosen based on the same occupancy types, both houses being lived in by families of four with similar occupancy patterns.

The reference house was built and insulated to minimum building code standards shortly before the Filter House. Comprising of an open plan living and kitchen area and a long hall with four bedrooms off either side, the building design is typical of those built in the area for the Department.

The reference house is heavily conditioned to maintain comfortable temperatures for the occupants, with a cassette system in the family room, a split-system in the kitchen and four reverse-cycle air conditioners in the bedrooms.

6.0 Energy Comparison – Predicted vs Actual

6.1 Predicted Electrical Use

The energy demand of the Filter House was predicted using two methods:

- **Method 1** – reductions in energy demand
- **Method 2** – load calculations

Method 1

The following table shows the breakdown of household energy, energy reduction strategies and the predicted savings achieved for different components of the Filter House and its occupants. The average energy use for a standard reference house in Broome was supplied in the competition brief.

This analysis predicted that the Filter House would use 46% of energy of that used in the standard reference house, or a 54% percent saving:

Broome average electrical use	6154 kWh per annum
Proposed saving	54%
Energy use design target	2830 kWh per annum

Method 2

The following table shows the demand based load calculations for the Filter House design. These figures were based on energy efficient appliances, light fittings and typical usage.

Component	Average % energy use standard reference house	Filter House reduction strategy	Reduced % energy use Filter House	Component % Saving
Heating/cooling	26 %	'cool cell' system	13 %	50 %
Hot water	31 %	Solar with gas boosting	5 %	84 %
Refrigeration	16 %	Best models use 30% of normal energy	6 %	70 %
Cooking	12 %	Energy rated gas appliances	10 %	16 %
Lighting	4 %	Energy efficient fittings	3 %	25%
Sundry	11 %	Energy efficient appliances	9 %	20%
TOTAL	**100 %**		**46%**	

Table 1. Predicted Reductions in Energy Demand for Filter House

Item	No	Wattage	Hours/ day	Wh/ day
Lights	12	11	6.0	792
Fridge	1	200	12.0	2,400
Microwave	1	700	1.0	700
Oven	1	2400	1.0	2400
Toasters	1	600	0.1	60
Washing machines	1	700	1.0	700
Driers	0			
Water pump	1	500	1.5	750
TV	1	150	4.0	600
Video	1	100	2.0	200
Stereo	1	60	4.0	240
Radio	1	20	3.0	60
Vacuum cleaner	1	1000	0.2	200
TOTAL				9,102

Table 2. Demand Based Load Calculations for the Design

The Filter House design annual load is therefore

$$\frac{\text{9,102 Wh x 365 days}}{1000} = \begin{array}{l}\text{3,322 kWh pa say}\\ \text{3,500 kWh per annum}\end{array}$$

6.2 Overall Predicted Electrical Energy Use

Figures from both methods of calculation are open to many variables. For use in generating design targets the higher figure of 3,500 kWh was chosen. Method 1 confirms this figure to be achievable from a demand reduction perspective.

In addition, further electricity savings were expected to be achieved through the use of the photovoltaic (PV) system. Taking the design target of 3,500 kWh per annum, this was expected to be reduced by 2,000 kWh (see below) resulting in an overall annual electricity use of **1,500 kWh**.

$$\frac{\begin{array}{c}\text{11 panels of 80 W by 6 hours}\\ \text{average per day x 365 days}\end{array}}{1000} = \begin{array}{l}\text{1,927 kWh}\\ \text{say } \textbf{2,000 kWh}\end{array}$$

6.3 Actual Electrical Energy Use

Data was collected over one year in the Filter House and a similarly sized reference house. Currently, data from the Filter House was available for the period August 2005 to May 2006, while the reference house data was only available from February 2006 to May 2006.

Extrapolation of the available data over the year gave estimates of the energy use demand, the energy provided by the PV panels to the Filter House and the mains energy use. Compared with the estimated energy use for the year with the reference house, the Filter House used **60%** less mains power.

For the months of February 2006 to April 2006, where actual data was available, the mains electrical energy use of the Filter House was significantly lower than the energy use of the reference house. The predicted energy use of both an average Broome house and the Filter House is under half of the measured values.

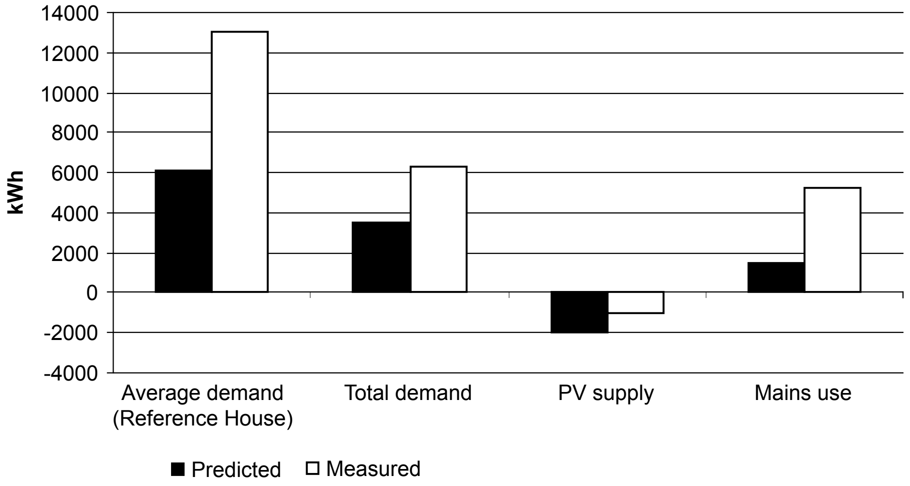

Figure 5. Annual Energy Use of Filter House and Reference House – Comparison of Predicted vs Measured Data (includes extrapolated data)

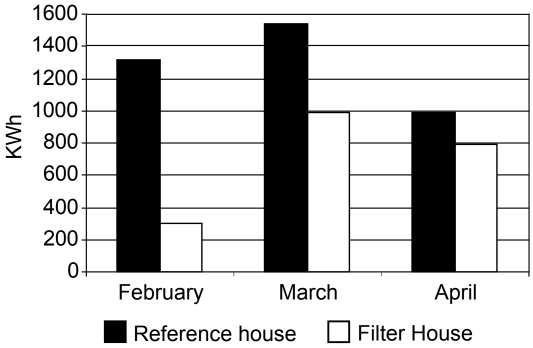

Figure 6. Electrical Energy Use Comparison of Filter House and Reference House (measured data)

6.4 Discussion of Electrical Energy Use

In comparison to the documented average energy use of an average residence in Broome in 2004, the Filter House used 14% less electrical mains power. Greater savings were achieved in comparison to the reference house, with the residents of the Filter House using 60% less mains power.

Broome average usage	6154 kWh per annum
Proposed Filter House average usage	1,500 kWh per annum
Calculated saving	76%
Metered house average usage	5281 kWh per annum
Metered saving	**14%**

Table 3. Energy Use Comparison between Predicted and Measured Data

The reference house used over twice as much mains power as the data supplied for the average residence in Broome. The expected variation in the average energy use due to occupant behaviour is up to an added 30%. If we assume that the reference house occupants are at the extreme of this range, you would expect the average household in Broome to consume approximately 9000 kWh, 50% higher than the original figure provided in the competition brief. It is likely that the Broome average energy use figure supplied in the competition brief was either outdated and that energy use has increased in recent years as a result of increased reliance on air conditioners or based on the energy use of houses in milder climates.

It is also noted that the demand based load calculations did not include heating and cooling, this is likely to have led to an underestimation in the predicted electricity load.

The energy supply from PV's was only half of the amount actually supplied when measured. Reasons for this are likely to include an overestimation of the hours that 80 W can be provided due to less sunny days or overshadowing, dust coverage and other maintenance problems and inefficiencies in the inverter.

7.0 Water Comparison – Predicted vs Actual

7.1 Predicted Water Use

The reduced usages noted below have been achieved by utilising a predicted **800 litres per day (on average)** of rainwater, and using water judiciously.

Table 5 shows the calculations of non-potable water use using figures supplied in the competition brief, with allowances for seasonal water consumption used in the garden. It is likely that the selection of plants ensured they required little watering which is reflected in the dry season figure.

The predicted potable water demand was 523 L/day, a 51% saving in comparison to average use (Table 6).

7.2 Actual Water Use

Data was extrapolated to cover the two months of the year not recorded in the August 2005 to May 2006 data.

	Broome average usage (L/day)	Filter House average usage (L/day)	Saving
Potable water use	277	222	20%
Non-potable water use	802	301	62%
TOTAL	1079	529	51%

Table 4. Overall Predicted Potable Water Demand

	Broome average daily non-potable water use (L)	Proposed use in dry season (L)	Proposed use in wet season (L)	Total proposed daily non-potable water use average over year (L)
WC	111	111	111	111
Washing machine	139	70	70	70
Other	20	20	20	20
Garden	532	200	0	100
TOTAL	802	401	201	301 (62% saving)

Table 5. Predicted Non-Potable Water Demand

	Broome average usage (L/day)	Proposed house average usage (L/day)	Proposed saving	Metered house average usage (L/day)	Metered saving
Potable water use	277	222	20%	-	178%
Non-potable water use	802	301	62%	-	127%
Mains Water Use	1079	529	51%	491	54%

Table 6. Measured and Predicted Potable Water Use

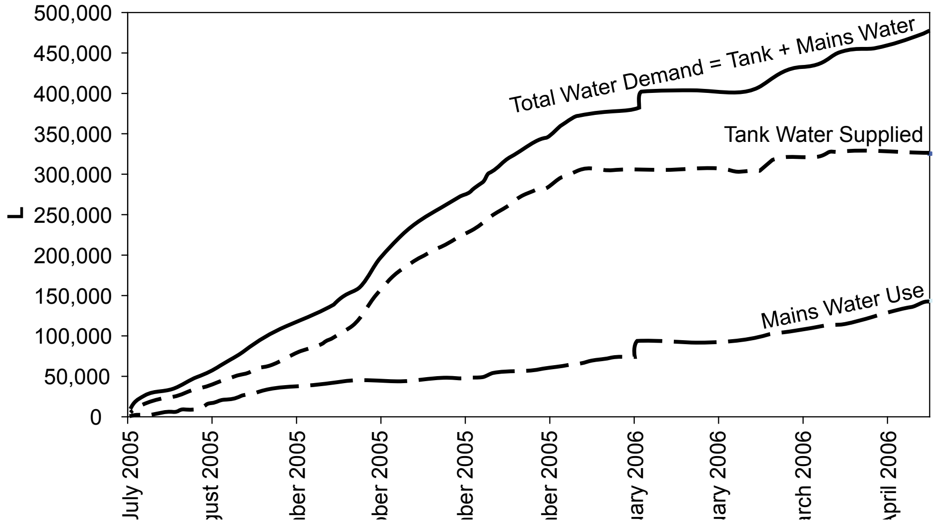

Figure 7. Measured Total Water Demand: Rainwater Supply and Potable Water Use

The mains water use measured at the Filter House was 491 L/day, 54% less than average.

The demand for both potable and non-potable water use was higher than both the average and predicted amounts; however the rainwater tank provided enough water to meet two thirds of the total demand. In total, 1,020 L/day of on-potable water was provided by the rainwater tank throughout the year (Figure 7). Individual demands for water use were not measured, only total mains use and rain water use. It is interesting to note that the total water use in the house was higher than expected, but this was buffered by the fact that the rainwater tank provided 30% more water than predicted, possibly a result of higher water demand or higher rainfall.

Aside from differences in behaviour, one known factor for the higher than expected demand is the change in the landscaping selection of plants away from the originally intended indigenous planting.

8.0 Conclusion

The Filter House has demonstrated a reduction in electrical energy use by 60% in comparison to the monitored Department of Housing and Works reference house and a 54% reduction in mains water use in comparison to the average Broome house.

The importance of accurate and recent benchmarking data should not be underestimated. If the reference house was not measured in this instance, the unreferenced competition brief energy benchmark would have been the only point of comparison between the houses.

Further investigation is needed to determine the factors that influenced the lower than expected output from the PV system.

It should also be noted that data collection relied upon the diligence of the residents. Accidental misuse of one of the data recorders in the reference house led to 6 months of data being lost. Future projects should ensure ease of data collection for the residents.

Biography

Chris Jensen BSc Environmental Science (Hons), MEnv, SV Accredited FirstRate Assessor, ABSA Accredited NatHERS Assessor is an Associate at Sustainable Built Environments (SBE). Chris brings a depth of environmental understanding to SBE, maintaining a keen interest in environmental sustainability in both his personal and working environments. His environmental knowledge spans across environmental management, efficient design, water, materials and energy use. Chris specialises in improving the energy efficiency of residential building envelopes and has extensive experience in identifying inefficiencies, material selection and improvement costing.

Nicki Taylor B Environmental Engineering (Hons), B Arts (Asian Studies) is also an Associate at Sustainable Built Environments (SBE) with the primary role as ESD Engineer. Nicki has a background in the development, review and use of assessments tools to measure building performance including STEPS, SDS, FirstRate, AccuRate, Green Star, Ecotect and VE and she studied Environmental Engineering at the Centre for Water Research, University of Western Australia. Nicki has worked with both state and local government bodies on the regulation and adoption of ESD principles in the building industry and has been involved in the training of professionals in ESD. At SBE, Nicki works as a Green Star professional, co-ordinating and preparing Green Star submissions. She is also responsible for applying the simulation tool 'Virtual Environment' to building designs in order to optimise building designs in terms of their energy efficiency.