COMPARATIVE SERVICE LIFE ASSESSMENT OF WINDOW SYSTEMS

Nigel P Howard and John C Burgess

The BRANZ research organisation investigated the environmental implications of 51 alternative archetype window and door systems commonly available in the Australian domestic market, and modelled their thermal performance for a wide range of Australian climates. The study considered the materials used, their production, manufacture and transport, operation and maintenance, durability and life-span and the heating or cooling energy needed to maintain comfort.

Keywords
windows, LCA, Cooling Degree Day (CDD), Degree day methodology, Heating Degree Day (HDD), Windows Energy Rating System (WERS)

1.0 INTRODUCTION

This paper is a summary of some of the findings of a recent Life Cycle Assessment study of standard windows and door systems sponsored by the Forest and Wood Products Research and Development Council. Both authors worked on the project under the independent Australasian building science research institute, BRANZ.

The full report is 49 pages in length and covers greater breadth and detail than that which is covered in this paper. The full report *Project Report - PR07.1047 Comparative Service Life Assessment of Window Systems* can be found on the internet at: http://www.fwprdc.org.au/content/pdfs/new%20pdfs/PR07.1047%20Final%20Report%20WEB.pdf

2.0 WINDOWS MATTER

Few studies have been conducted internationally on the full life cycle environmental impact of window systems. Mostly they have been conducted in Europe or in the USA where the climate is generally more severe for heating or cooling than many parts of Australia.

Windows can contribute to the environmental impact of buildings very significantly. The UK Green Guides to specification show that they represent about 5 per cent of the materials impacts of both housing (Howard and Anderson, 2000) and commercial buildings (Anderson and Shiers, 2002), with the proportion being much higher for buildings utilising curtain wall fenestration. Substituting an opaque wall element with a window or curtain wall glazing typically doubles the materials impacts of the wall (Howard, 1996) (and more than doubles the financial cost).

In addition, external windows and doors let daylight into buildings, give occupants the benefit of a view and sense of connection to the outside, and contribute substantially to the aesthetic of the building, both internally and externally. Windows and doors are usually less insulating than opaque elements and permit more thermal transmission directly through building envelopes, and indirectly through ventilation. Operable windows can give occupants personal control of their internal environment and can be a key component of a natural ventilation strategy for a building.

This article describes research into the life cycle environmental impacts of windows and doors used in Australia. The study investigated 51 archetype windows in a wide variety of climates, as represented by the state and territory capital cities across Australia.

3.0 THE RESEARCH

The research was conducted by BRANZ on behalf of the Forest and Wood Products Research and Development Corporation over the period January to May 2007 (Howard, N P, Burgess, J, 2007). The main research tasks were:

- Review of the windows/doors markets to determine a list of representative archetypes (target number 50, actual number 51)
- Conduct a literature review on the service life performance of window systems and life cycle environmental impact of window systems
- Collate the materials' embodied impacts life cycle assessment data relevant for Australia; both initial and taking account of replacements over the life
- Assess the operational energy implications of the different window systems in different climate zones (using Australian capital cities as state/territory examples)
- Collate all of the results over the full life cycle of the units to identify the optimum window system choices for each location
- Report findings to the funding body.

The project benefited from the support of an advisory group of stakeholders from the window industry (AWA and WADIC), from the timber industry (TDA) and LCA experts from RMIT and CSIRO. They were consulted on the functional unit, the selection of archetypes representative of the Australian market, the methodology and results of the study and they provided comment, which was assimilated into the final report.

4.0 THE ARCHETYPES

The archetypes selected for inclusion in the study are shown in Table 1 below. These comprised different styles and configurations of windows and doors, and

	Door/ Window	Fenestration type	Height	Width	Panes	Framing	Glass 1 type	Glass 1 thickness	Gap between panes	Gas fill	Glass 2 type	Glass 2 thickness	Market share (%)
1	Door	DC (F)	2100	1800	1	Al	►	5	0	0	0	0	0.60
2	Door	DC (F)	2100	1800	2	Al	►	5	12	0	►	5	0.01
3	Door	DC (F)	2100	1800	1	♦	►	5	0	0	0	0	1.20
4	Door	DC (F)	2100	1800	1	Al-S	►	5	0	0	0	0	0.01
5	Door	DC (F)	2100	1800	1	PVC	►	5	0	0	0	0	0.10
6	Door	DC (F)	2100	1800	2	PVC	►	5	12	0	►	5	0.10
7	Door	DC (F)	2100	2700	1	Al	►	5	0	0	0	0	5.00
8	Door	DC (F)	2100	2700	2	Al	►	5	12	0	►	5	0.01
9	Door	DC (F)	2100	2700	1	♦	►	5	0	0	0	0	1.00
10	Door	SP (R)	2100	2700	1	Al-S	►	5	0	0	0	0	0.01
11	Door	BiFold	2100	3600	1	Al	►	5	0	0	0	0	1.20
12	Door	BiFold	2100	3600	2	Al	►	5	12	0	►	5	0.01
13	Door	BiFold	2100	3600	1	♦	►	5	0	0	0	0	0.10
14	Door	BiFold	2100	3600	1	Al-S	►	5	0	0	0	0	0.01
15	Window	Horizontal Slider	1200	1800	1	Al	•	6.7	0	0	0	0	0.01
16	Window	Horizontal Slider	1200	1800	2	Al	■	4	6	Ar	■	4	0.01
17	Window	Horizontal Slider	1200	1800	1	Al	■	4	0	0	0	0	61.00
18	Window	Horizontal Slider	1200	1800	1	Al	Toned	5	0	0	0	0	4.00
19	Window	Horizontal Slider	1200	1800	1	Al	L	6.38	0	0	0	0	0.20
20	Window	Horizontal Slider	1200	1800	2	Al	■	4	12	0	■	4	0.10
21	Window	Awning, toilet	900	600	1	Al	■	4	0	0	0	0	9.00
22	Window	Awning, toilet	900	600	1	Al	Toned	5	0	0	0	0	0.50
23	Window	Awning, toilet	900	600	2	Al	■	4	12	0	■	4	0.01
24	Window	Awning, toilet	900	600	1	♦	■	4	0	0	0	0	4.00
25	Window	Awning, toilet	900	600	2	♦	■	4	6	0	■	4	0.01
26	Window	Awning, toilet	900	600	1	♦	Toned	5	0	0	0	0	0.10
27	Window	Awning, toilet	900	600	2	♦	■	4	6	0	■	4	0.01
28	Window	Awning, toilet	900	600	1	Al-S	■	4	0	0	0	0	0.01
29	Window	Awning, toilet	900	600	2	Al-S	■	4	12	0	■	4	0.01
30	Window	Awning, toilet	900	600	1	PVC	■	3	12		■	3	0.10
31	Window	Casement	1200	1200	1	♦	■	4	0	0	0	0	1.50
32	Window	Casement	1200	1200	1	♦	Toned	5	0	0	0	0	0.10
33	Window	Casement	1200	1200	1	♦	L	6.38	0	0	0	0	0.01
34	Window	Casement	1200	1200	2	♦	■	4	6	0	■	4	0.01
35	Window	Casement	1200	1200	1	Al-S	■	4	0	0	0	0	0.01
36	Window	Casement	1200	1200	1	Al-S	Toned	5	0	0	0	0	0.01
37	Window	Casement	1200	1200	1	Al-S	L	6.38	0	0	0	0	0.01
38	Window	Casement	1200	1200	2	Al-S	■	4	12	0	■	4	0.01
39	Window	Double Hung	1200	900	1	Al	■	4	0	0	0	0	3.00
40	Window	Double Hung	1200	900	1	Al	Toned	5	0	0	0	0	0.10
41	Window	Double Hung	1200	900	1	Al	L	6.38	0	0	0	0	0.05
42	Window	Double Hung	1200	900	2	Al	■	4	12	0	■	4	0.01
43	Window	Double Hung	1200	900	1	♦	■	4	0	0	0	0	6.00
44	Window	Double Hung	1200	900	1	♦	Toned	5	0	0	0	0	0.10
45	Window	Double Hung	1200	900	1	♦	L	6.38	0	0	0	0	0.10
46	Window	Double Hung	1200	900	2	♦	■	4	6	0	■	4	0.01
47	Window	Double Hung	1200	900	1	Al-S	■	4	0	0	0	0	0.01
48	Window	Double Hung	1200	900	1	Al-S	Toned	5	0	0	0	0	0.01
49	Window	Double Hung	1200	900	1	Al-S	L	6.38	0	0	0	0	0.01
50	Window	Double Hung	1200	900	2	Al-S	■	4	12	0	■	4	0.01
51	Window	Double Hung	1200	900	2	PVC	■	4	12	0	■	4	0.50

•	Laminated low-e						
■	Clear annealed	►	Toughened	Al-S	Al-Skinned	SP (R)	Sliding Patio (Ranchslider)
♦	Timber	Al	Aluminium	DC (F)	Double Casement (French)		
		Ar	Argon	L	Laminated		

Table 1. Archetypes studied

have different common sizes, are single and double glazed, with 4 different frame types (aluminium, aluminium skinned softwood timber, hardwood timber and PVC), with different glazing types and thicknesses. The archetypes were selected for their prevalence in the market together with their spanning of the range of variations available in Australia.

Although the advisory group only included a single low-E, single glazed archetype, as this technology has minor market penetration in Australia, it did perform well in most climate conditions and especially in the marginal heating/cooling conditions.

4.1 Service Life Performance

Although complete window systems are required to have a lifetime of 15 years under the New Zealand Building Code there is no specific lifetime prescribed in Australia. However, with appropriate maintenance they can last considerably longer, with examples of largely original timber windows still existing in some early colonial dwellings that are 200 years old. The windows market is currently dominated by aluminium horizontal sliding windows that can continue to perform well past the expected 15 year mark, provided maintenance of the 'mohair' sliding seals and hardware is performed.

No studies of Australian window lifetimes could be found. International studies have found that the anticipated life expectancy of the framing used in window systems varies with type. One published study ((Brown et al, 1999) showed an expected lifetime of 45 years for aluminium-skinned timber, 40 years for aluminium, 35 for timber and 22.5 for PVC. Examples of window/door longevity across a range of Australian climates indicate that the life expectancy of windows varies greatly, and that, maritime environments will, for example, degrade some window constructions significantly faster than would a dry alpine area.

The maintenance of windows with the replacement of seals at 5 yearly intervals, external aluminium or PVC beads at 15 years, and complete Insulated Glazing Units (IGUs) at 20 year intervals is a major factor governing the operational life of a window system.

Chemical degradation of window framing systems can occur from the incidence of high levels of ultraviolet radiation. In particular, plastics materials, such as PVC framing, weather seals, glazing seals, and surface coatings suffer. This is both a problem at low (equatorial) latitudes due to high ultraviolet (UV) radiation intensity, and also at higher latitudes that are increasingly being affected by tropospheric ozone depletion (commonly referred to as the 'ozone hole'). The UV degradation causes shrinkage of some sealing and beading 'rubbers' which leads to both air infiltration and water ingress.

Double glazing or IGUs as they are referred to internationally, are known to have a 30-35 year lifetime in countries where international-standard durability assessments are regularly performed. The Australian IGU industry is still relatively young, and there has been very little penetration of double glazing into the domestic market. Although international best practice in sealant use and IGU design is being adopted, until a comprehensive survey of Australian domestic IGU lifetime can be performed, the lifetime of IGUs can only be assumed to be for the lesser period of 20 years within the Australian environment.

The Australian IGU industry has not yet adopted a robust means (such as the European standard EN1279-3) for assessing the argon gas loss from within double glazed units. Until Australian built units have been accredited against EN1279-3, they must be assumed to lose gas at more than 1 per cent per year, (the requirement of EN1279 Part 3) which leads to a slow decrease in thermal performance.

Many consumers believe that aluminium and PVC framed windows and doors, together with aluminium skinned timber fenestration, are essentially maintenance free, but this is actually not the case. The aluminium window manufacturing industry recommends cleaning windows at regular intervals (monthly in some states and territories) with warm soapy water to remove surface contaminants and maintain the anodised or powder coated aluminium finish. Similarly the timber window industry recommends maintaining the finish coats on the exterior joinery to shield the timber from the deleterious effects of the weather. Maritime, congested-urban, dusty, and heavy industrial environments can be particularly harsh on window products exposed to the exterior environment, as well as exposure to high levels of UV light, as discussed above.

The window systems that can be seen to perform the best in terms of service life currently are horizontal sliding windows made of aluminium-skinned timber, followed by aluminium, then timber and finally PVC. This conclusion is based on non-Australian data, but is still considered relevant to Australia.

	Service life in years for various window components								
Frame Material	**Frame/ Sash**	**Frame/ sash joints**	**Wedges, brushes, seals**	**Hardware**	**Glass**	**IGU**	**Reveal liners**	**Powder Coat**	**Paint**
Aluminium	35	15	5	15	35	20	15	15	5
Timber	35	15	5	15	35	15	15	15	5
Aluminium skinned Timber	45	15	5	15	45	20	15	15	5
PVC	22.5	15	5	15	=	20	15	15	5

Table 2. Assumed lifetime of components

5.0 ENVIRONMENTAL PERFORMANCE

A full life cycle environmental impact assessment adapted to Australian data and compliant with ISO 14041 (ISO, 1998) and with the BRE Environmental Profiles Methodology (Howard et al, 1999) was used to assess the different window system archetypes. This approach was chosen to ensure that the LCA data used for all of the materials and components that comprise the studied window systems was compiled consistently and compatibly up and down the supply chain, as well as compatibly with the data for operational performance of the window systems.

The life cycle assessment was compiled using Australian data wherever possible, supplemented with international data where Australian data were unavailable. The data were compiled within the Sima Pro LCA software, drawing from the Australian and international datasets provided with that software. Australian data were available for all of the major mass components of the window systems. Where international data were used, this was contextualised to Australia as far as possible. For example, a German process using German electricity would be amended to use Australian electricity.

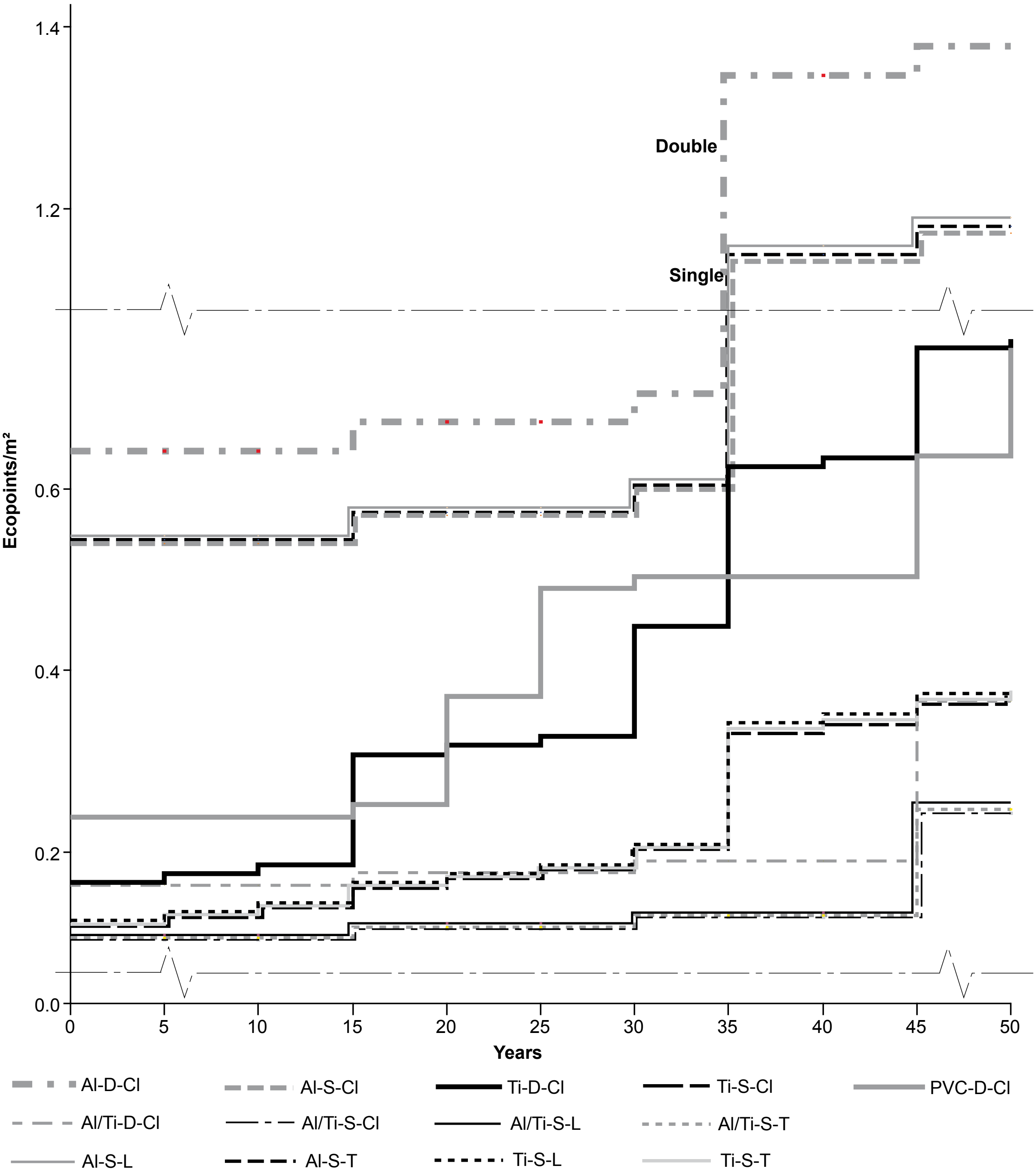

Figure 1. Life cycle embodied ecopoints for double hung windows

he impact assessment entailed classification and characterisation of the different environmental impact parameters, normalisation against the total annual impacts of an average Australian citizen and weighting the relative importance of the different impacts using similar weightings to those developed for use with the Green Star Rating System for different climate zones. The final results are expressed in both Carbon Dioxide Equivalent (CO_2-E) terms and Australian Ecopoints, with the carbon dioxide being for those interested uniquely in the climate change implications, and Ecopoints for those interested in the full range of environmental impact categories (where 100 Ecopoints equates to all of the impacts of an average Australian for a year). To illustrate how Ecopoints work, if a particular window system's full life cycle impacts are expressed as 1.6 Ecopoints/m^2 of window system, then 200 m^2 of this type of window would cause 320 Ecopoints of total environmental impact i.e. that equivalent to the impact of 3.2 average Australians (from everything they do) over a year.

The impact categories included in the study were:

- Global Warming (GWP100 years)
- Ozone Depletion Potential (ODP)
- Human toxicity
- Fresh water aquatic ecotoxicity
- Marine aquatic ecotoxicity
- Terrestrial ecotoxicity
- Photochemical oxidation
- Acidification
- Eutrophication

The characterization method used was CML2000 from University of Leiden (CML2000).

Unsurprisingly, the most significant factor in the life cycle performance of the windows for both their materials impacts and their operational energy performance was the size of the window or door. The results in this paper are therefore all presented per square metre of window system.

5.1 Materials Impacts

Figure 1 shows how the embodied environmental impacts from the materials accumulate over the life of different variants of the double-hung window. At year 0 on the x-axis the windows are installed – this is the initial embodied Ecopoint score, showing that the aluminium framed windows cause the highest initial impacts. Over the life of the windows, as different components are replaced during maintenance the Ecopoints accumulate for each component replaced. By the end of 50 years all of the windows have been replaced at least once and the aluminium coated timber and timber framed windows have caused least impact, with the single glazed having less impact than the double glazed. However, the materials impacts take no account of the energy saved by the double glazing over its life.

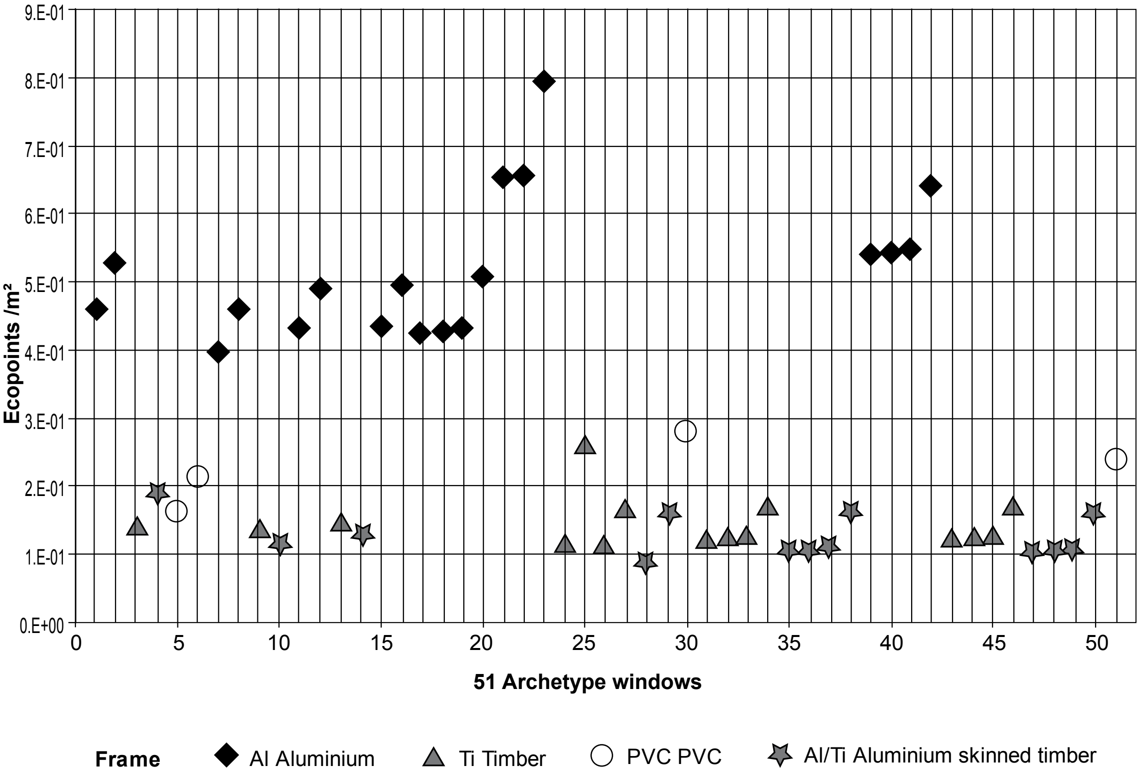

Figure 2. Embodied ecopoints per square metre of window/door

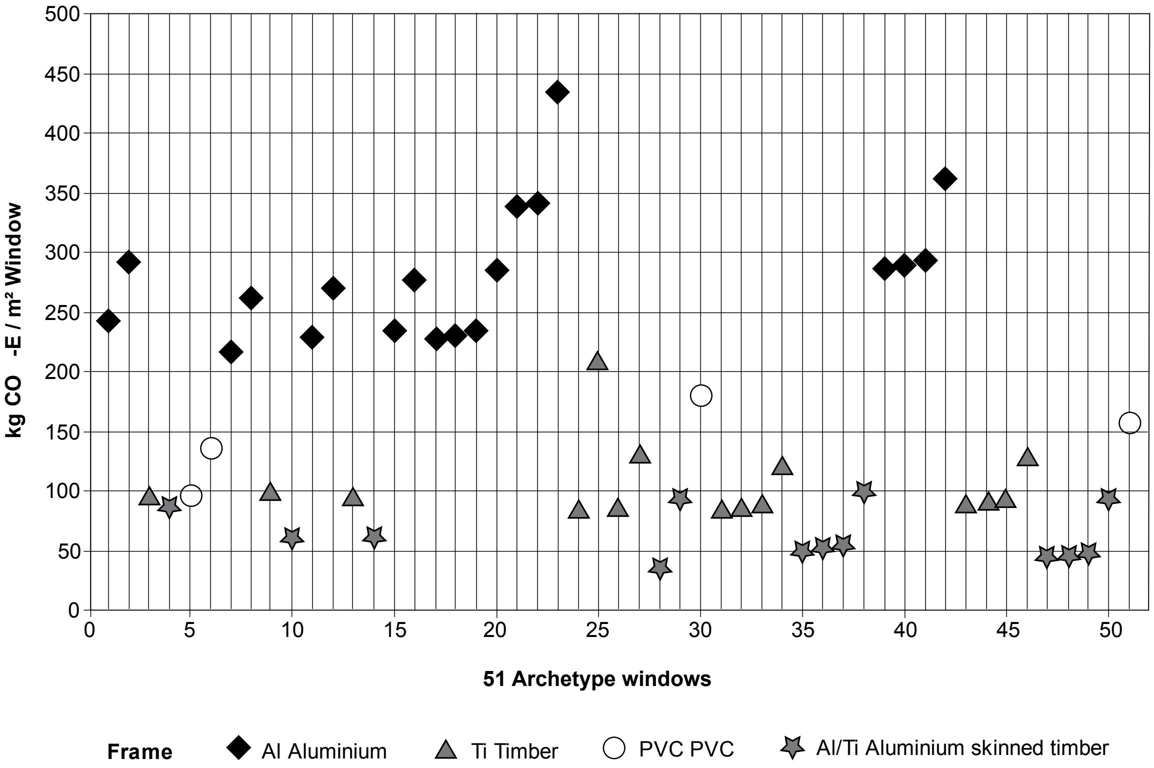

Figure 3. Embodied carbon dioxide per square metre of window/door

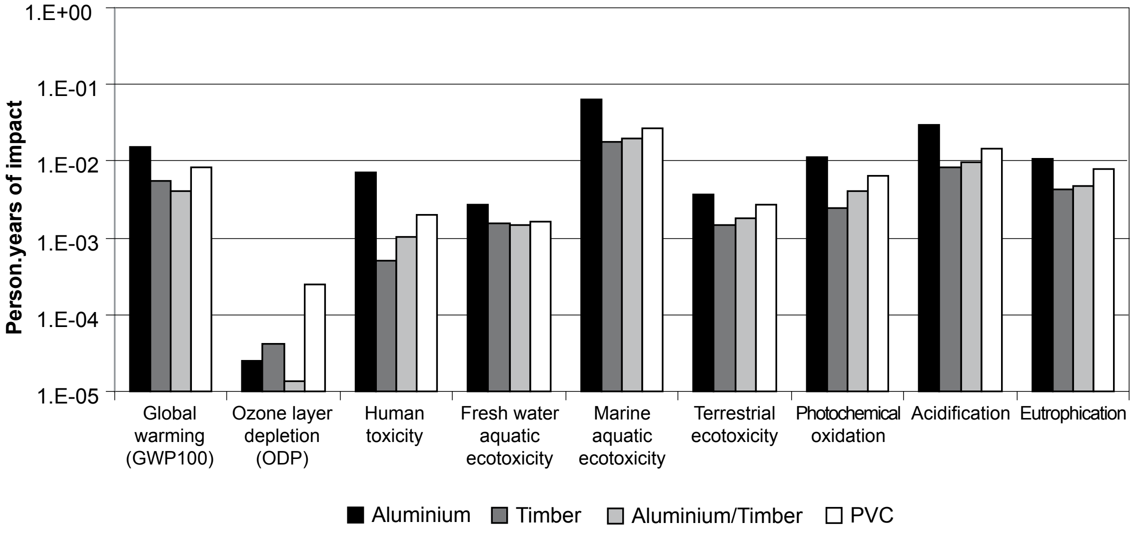

Figure 4. Normalised embodied impacts by category

Figures 2 and 3 show the initial embodied (materials) impacts from the windows in terms of Ecopoint for all impact categories, and CO_2-e for climate change impact.

As expected, there is a good correlation – materials production and transport lead to energy-related impacts that tend to dominate the materials impacts of which CO_2-e is the highest weighted impact.

Figure 4 illustrates how the different window systems contribute to each of the impact categories that comprise the Ecopoint.

5.2 Operational Energy Implications

The thermal performance of the archetypes was assessed using the degree days methodology. For this method, the base temperature for the Heating Degree Day (HDD) was 18°C and 24° for Cooling Degree Day (CDD). It is the design process that makes allowances for window and door orientation, overshading, microclimate, humidity, neighbouring buildings and many other factors that can provide a wide variety of results beyond the resolution of this study, even if the location were very accurately described. In retrofitting existing buildings that are not designed to shade peak summer solar gains, windows with reduced solar heat gain coefficient may provide some mitigating advantages, but these will be less than those from suitable external shading.

The thermal performance of the archetypes was assessed using the **degree days** methodology. Thermal resistance (R) values have been calculated for each of the archetypes using the Windows Energy Rating System (WERS thermal performance data adjusted for window size of the windows). The R-value is the reciprocal of the window U-value, the parameter rated by WERS. Diffuse solar gain has been taken into account and it is assumed that in a good design, direct solar gain would be shaded externally. It has been assumed that the R value (or U-value) does not degrade with maintenance performed to maintain the leak tightness of the windows. For the one archetype assuming an Argon filled IGU, it has been assumed that the thermal performance is not degraded by leakage of the Argon fill – BRANZ believe this is a valid assumption over a 20 year period. Although the degree day method might be criticized as somewhat simplistic, it has the merit of only assessing the window's performance and not the building that it is installed within. Several other alternative, more complete methods were investigated before settling on this approach, but it proved impossible to factor out the effects of the building from those for the window system.

Figures 5 and 6 show the cooling and heating Ecopoints that would arise over 50 years for each of the 51 archetype windows and doors in the most demanding climate, in the least demanding climate and for the average of all of the locations studied. For cooling, the most demanding climate is in Darwin and the least demanding is in Melbourne. For heating these reverse, with Melbourne being the most demanding and Darwin, the least.

These results reveal that the choice of window system appears to matter more in climates requiring heating. This occurs because window systems always add solar gain through short-wave radiation (including light) transmission which reduces the need for heating and increases the need for cooling. As a result, a higher performance window (more insulating and/or with higher solar gain coefficient) admits more solar gain and retains it in the building beneficially for heating compared to a poorer performing window. In a cooling scenario a poorer performing window will admit a similar solar gain from short-wave radiation transmission to the high performance window. The additional cooling needed due to increased heat conduction through the poorer performing window system is minor compared to the short-wave radiation transmitted gain. The additional cooling needed due to increased heat conduction through the poorer performing window system is small compared to the short-wave radiation transmitted gain. As a result, the performance of the window system matters less for cooling than for heating.

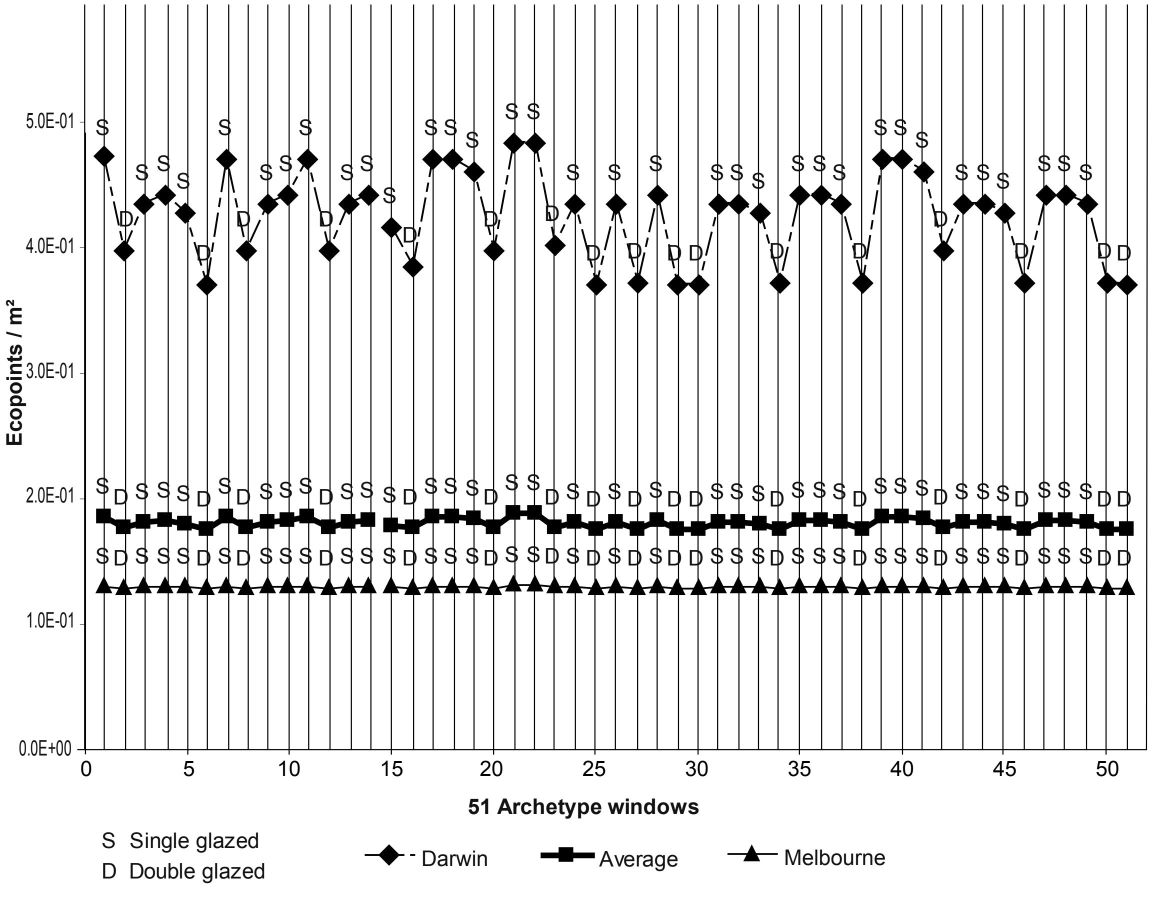

Figure 5. Cooling ecopoints per square metre

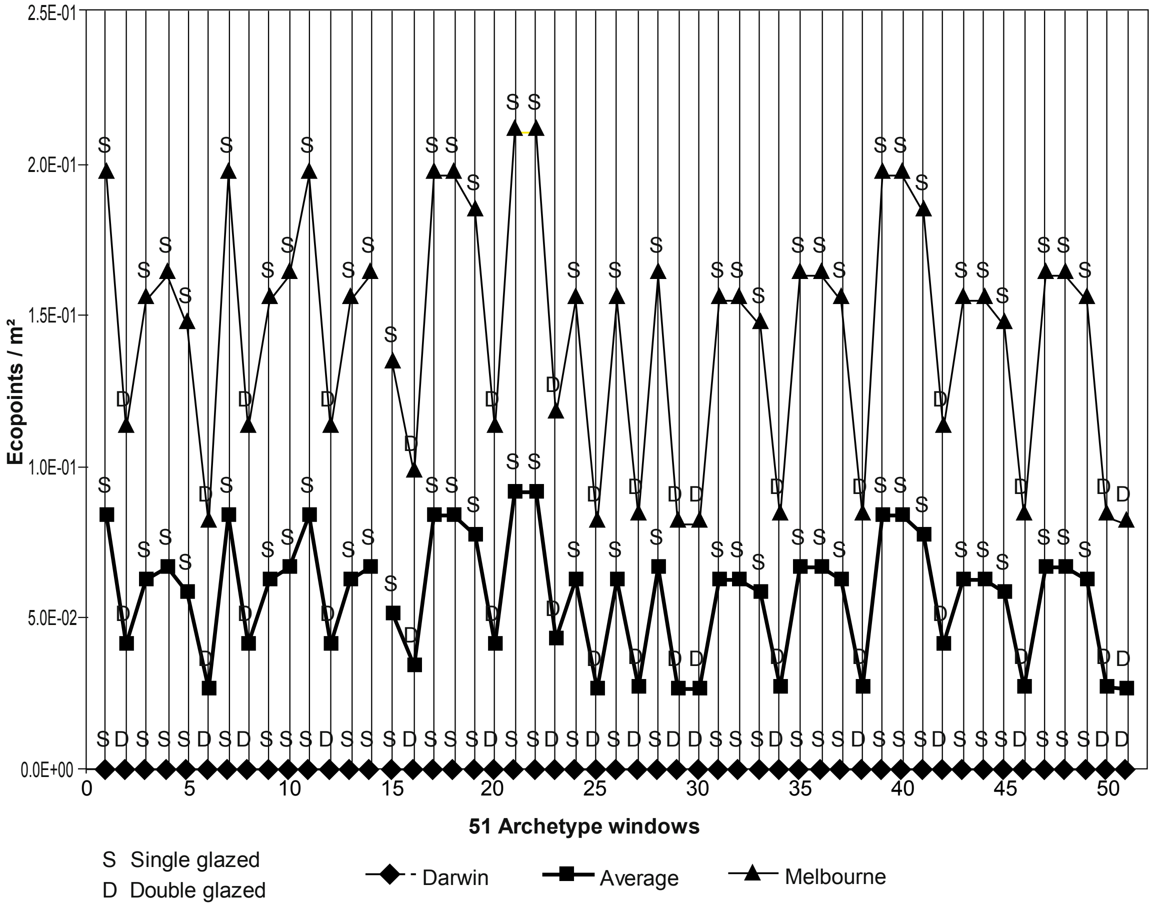

Figure 6. Heating Ecopoints per square metre

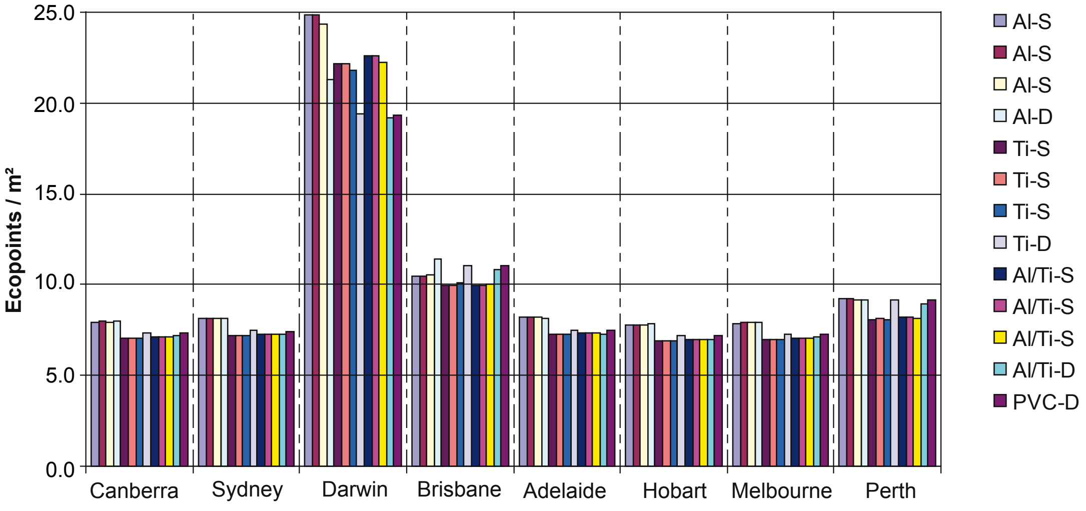

Figure 7. Fifty year life cycle embodied and operational cooling only for double-hung windows

The dominant factors in window system performance in order of importance are:

1. whether the window is single or double glazed
2. window frame type
3. window configuration.

6.0 THE LIFE CYCLE STORY

There are two approaches to LCA described as 'consequential' and 'attributional' A **consequential LCA** study might consider all kinds of changes that could happen in the life of a product, and involves many assumptions/presumptions about the future. However the study reported here was an **attributional LCA** study, that is, all the data is based on current conditions.

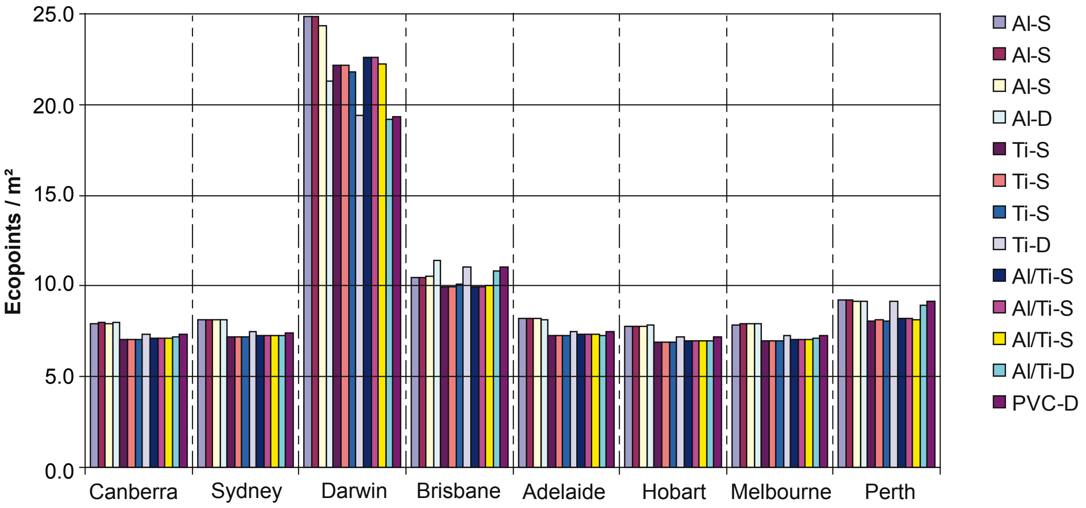

Figure 8. Fifty year life cycle embodied and operational heating only for double-hung windows

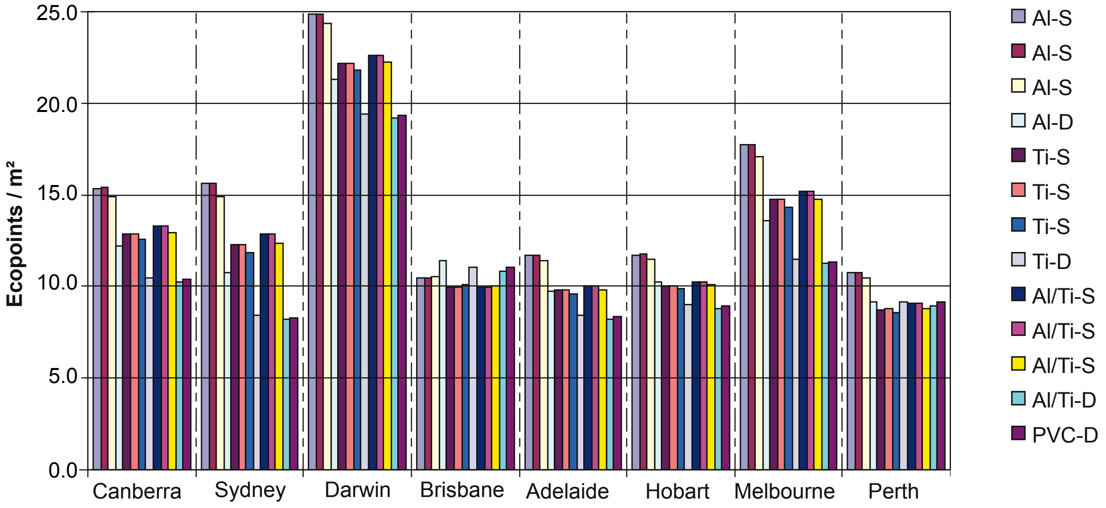

Figure 9. Fifty year life cycle embodied and operational heating and cooling for double-hung windows

Figures 7 and 8 combine the life cycle materials impacts with the operational energy impacts for the heating and cooling situations respectively, using the different variants (frame type and single/double glazed) of the double hung window as an example.

Figure 7 reveals that only in Darwin is the cooling load high enough to justify the use of high performance glazing systems on the basis of cooling loads alone. In all other locations environmental benefits from reduced cooling load are not sufficient to justify and pay back the additional environmental impacts from the production of high performance window systems. However, it is heating load that predominates.

Figure 8 reveals that in all cities except Darwin and Brisbane, the reduced heating load from high performance window systems pays back the additional environmental impacts from their production. The case is particularly strong for Melbourne, Sydney and Canberra. The case is not as strong as expected for Hobart and this is due to the extensive use of hydroelectricity and the use of wood as a fuel. (Wood is an almost renewable fuel: although trees give off carbon dioxide to the atmosphere when burning, they absorb carbon dioxide and solar energy while growing. It is not 100 per cent renewable because it still needs to be transported using non-renewable fuels to its point of use).

Figure 9 combines the materials (embodied) impacts with the impacts from both heating and cooling. It reveals a strong case for the use of high performance glazing in Melbourne, Sydney and Canberra to reduce heating loads, and in Darwin to reduce cooling loads. High performance glazing is also justified in Adelaide and Hobart for reduced heating loads. In Perth the case is barely justified and in Brisbane, high performance window systems are unlikely to recover the additional impacts from their production from energy savings.

7.0 FINDINGS

Location	Heating / Cooling	Single / Double	Frame Type
Canberra	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber, PVC
	both	double	aluminium skinned timber, timber, PVC
Sydney	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber, PVC
	both	double	aluminium skinned timber, timber, PVC
Darwin	heating	single	aluminium skinned timber, timber
	cooling	double	aluminium skinned timber, timber
	both	double	aluminium skinned timber, timber, PVC
Brisbane	heating	single	aluminium skinned timber, timber
	cooling	single	aluminium skinned timber, timber
	both	single	aluminium skinned timber, timber, PVC
Adelaide	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber, PVC
	both	double	aluminium skinned timber, timber, PVC
Hobart	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber, PVC
	both	double	aluminium skinned timber, timber, PVC
Melbourne	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber, PVC
	both	double	aluminium skinned timber, timber, PVC
Perth	heating	double	aluminium skinned timber, timber, PVC
	cooling	single	aluminium skinned timber, timber
	both	single	aluminium skinned timber, timber

Table 3. Best life cycle environmental choices

In all cases where double-glazing is justified, laminated low-E glazing is also justified and would probably perform well in all frame types.

Table 3 summarises the life cycle results and can be used to select window systems for optimum life cycle environmental performance. It should be noted that capital cities were used as the locations representing each state. Because climate can vary dramatically over many of the larger states, users should take this into account in selecting the optimum window. It should be noted that the results of this work are provided on the basis of best available data at the time of conducting the research. As new data emerges for materials, products and for modelling energy performance of windows/doors it is will be necessary for these results and conclusions to be updated.

The study found that:

- In most locations requiring significant cooling (Darwin) or heating (Melbourne, Adelaide, Canberra and double glazing is justified.
- Market-leading aluminium-framed windows performed consistently worse than alternatives.
- Timber-framed windows and aluminium-skinned, timber-framed windows performed best with PVC windows also fairly competitive environmentally.

The main surprises came for the benign climates in parts of Queensland where heating and cooling loads can be very low. In these locations the additional environmental impacts from the production of double-glazing systems may not be recovered from additional energy savings over the life of the windows. Also, in Tasmania, the high proportion of hydroelectric power and wood fired heating reduces the expected benefits from double-glazing systems that would be expected for the prevailing climate.

8.0 CONCLUSION

The optimum choice of window system for its life cycle environmental impacts should depend on the location and climate and expectations of the need for heating or cooling.

High performance windows are justified in most locations in Australia either for reducing cooling loads (Darwin) or reducing heating loads (Melbourne, Sydney, Canberra, Adelaide, Hobart). In parts of Queensland and probably Western Australia, the climate may be sufficiently benign for both heating and cooling to not justify high performance window systems.

When it comes to choice of frame, aluminium skinned softwood is the best overall performer, with hardwood framed windows a close second and PVC also environmentally competitive. The market leading aluminium framed window is not the best performer environmentally, but over the full life cycle of the window the difference in environmental impact can be marginal in climates requiring little heating or cooling, but significant where greater heating or cooling is required. The performance gains provided by 'thermally broken' aluminium frames might significantly reduce this performance gap.

Window configuration proved to be of relatively minor significance compared to single/double glazing and frame type. Window size was a dominant factor and the size; orientation and shading, how they are integrated into a building design and how the building is serviced and controlled for comfort must all be considered. No consideration of cost has been made in this study

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REFERENCES

Howard, N, Anderson J, 2000, *The Green Guide to Housing Specification*, BR 390, CRC, 2000, Garston, Watford, UK.

Anderson, J, Shiers, D, 2002, *The Green Guide to Specification*, Edition 3, Blackwell, Garston, Watford, UK.

Howard, NP, 1996, *Embodied Energy and Consequential CO_2 in Construction*, Proceedings of the 1996 International Symposium of CIB W67, Energy and Mass Flow in Buildings, Vienna, Austria, 4-10 August 1996.

Howard, NP, Burgess, J, 2007, *Project Report - PR07.1047 Comparative service life assessment of window systems*, prepared for the Forest and Wood Products Research and Development Corporation, viewed November, 2007, http://www.fwprdc.org.au/content/pdfs/new%20pdfs/PR07.1047%20Final%20Report%20WEB.pdf

Brown, AW, Allwinkle AJ, Weir, GF, 1999, Durability of Building Materials and Components 8, Institute for Research in Construction, Ottawa, Canada.

ISO, 1998, International Organisation for Standardization, *14041-98 Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis*, International Organization for Standardization, Geneva, Switzerland.

Howard, N, Edwards, S, Anderson J, 1999, *BRE Methodology for Environmental Profiles of Construction Materials*, Components and Buildings, BR 370, CRC Garston, Watford, UK.

CML, *CML2000 - Institute of Environmental Sciences* (CML) – University of Leiden, Netherlands. http://www.leidenuniv.nl/cml/ssp/databases/cmlia/index.html

GLOSSARY

CO_2e or **CO_2eq** is Carbon dioxide equivalent, CO_2eq or CO_2e, is an internationally accepted measure that expresses the amount of global warming of greenhouse gases (GHGs) in terms of the amount of carbon dioxide (CO_2) that would have the same global warming potential.

(Source: taken from http://en.wikipedia.org/wiki/Carbon_dioxide_equivalent)

Cooling degree day is a unit used to relate the day's temperature to the energy demands of airconditioning. Cooling degree days are calculated by subtracting 18ºC from a day's average temperature. Cooling degree days can be used to compare the current summer to past summers. Hence, by studying degree day patterns in your area, you can evaluate the increases or decreases in your heating or air-conditioning bills from year to year.

(Source: taken from http://www.daviddarling.info/encyclopedia/M/AE_modified_degree-day_method.html)

Degree day methodology uses a unit for measuring the extent that the outdoor daily average temperature (the mean of the maximum and minimum daily dry-bulb temperatures) falls below (in the case of heating, see heating degree day), or rises above (in the case of cooling, see cooling degree day) an assumed base temperature, normally taken as 18°C unless otherwise stated. One degree day is counted for each degree below (for heating) or above (in the case of cooling) the base, for each calendar day on which the temperature goes below or above the base.

(Source: taken from http://www.daviddarling.info/encyclopedia/M/AE_modified_degree-day_method.html)

Heating degree day (HDD) is the number of degrees per day that the daily average temperature (the mean of the maximum and minimum recorded temperatures) is below a base temperature, usually 18°C, unless otherwise specified. Annual patterns of heating degree days can be used to determine indoor space heating requirements and heating system sizing. Total HDD is the cumulative total for the year/heating season. The higher the HDD for a location, the colder the daily average temperature(s).

(Source: taken from http://www.daviddarling.info/encyclopedia/M/AE_modified_degree-day_method.html)

Thermally broken aluminium window/door frames are designed to have internal and external metal faces disconnected thermally by the use of less conductive material. This reduces' thermal bridging' and thus avoids excessive heating and cooling energy being transmitted through the frame.

continued over

Window Energy Rating Scheme (WERS) enables windows to be rated and labelled for their annual energy impact on a whole house, in any climate of Australia. A New Zealand variant of WERS, the 'Window Efficiency Rating Scheme', is also available. To participate in WERS, window makers must obtain energy ratings for their products from a rating organisation that is accredited by the WERS Management Committee.

(Source: http://www.wers.net)

BIOGRAPHIES

John Burgess has worked as a scientist in building physics for 20 years with BRANZ Ltd in New Zealand, BRE in the UK, and briefly with LBNL in California. He has developed testing protocols and facilities for insulating glazing systems in New Zealand and South East Asia for the New Zealand double glazing industry and New Zealand Central Government. John is the author of a number of papers on weather tightness, double glazing and thermal performance of windows, and has been involved with the development of window performance rating tools and space and water heating rating tools for industry and Central Government in New Zealand. He has been on numerous standards committee in New Zealand and Australia including windows, glass, curtain walls and thermal performance standards.

Nigel Howard is a former director of the Centre for Sustainable Construction in the UK responsible for BREEAM rating tools, ECOHOMES, the UK Green Guides to Specification (Residential and Commercial) and the ENVEST design tool. He also contributed to the design teams for many award winning buildings working with many of the UK's top architects. He moved to the USA in 2001 as Vice President for the US Green Building Council, responsible for the LEED environmental rating tools – he directed the commercialization of LEED, steering it through 30-fold growth over 4 years, expanding from 1 to 5 LEED versions and licensing to Canada and India. He moved to Australia in 2006 and is working with BRANZ to establish a Life Cycle Assessment consultancy business. He is Vice President of the Australian Life Cycle Assessment Society, working closely with the Australian construction materials sector to establish an Australian National Life Cycle Inventory Database and practical LCA based tools for designers and specifiers.

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