SM3570/6

LCA-based Windows Calculator

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About This Report

Title

LCA-based Windows Calculator

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Abstract

This project is part of the 'Criteria Development and Embedding System' phase of work within Beacon's Systems work stream. The goal of the overall systems strategy is to develop systems that enable a house to perform to the HSS High Standard of Sustainability™ (HSS™) as defined by Beacon [1]. The aim of this research was to provide Beacon with a working prototype of a tool that allows the quantification of (environmental) sustainability on a system level, based on a specific functional unit (a defined window (geometry) with a certain thermal resistance (R-value in W/ m2°C)) over a lifespan of 50 years. The methodology used to calculate the environmental impact is Life Cycle Assessment as defined in AS/NZS ISO 14040 and 14044.

This project has resulted in the development of an Excel-based window calculator, offering a simple interface for the user to define a specific window. Based on this information, the calculator gives the environmental impact of the window over a specific lifespan, as well as the resulting R-value. The development of a prototype window calculator aims to provide environmental data that will guide the development of new window systems and to lay the foundation for a comprehensive system to facilitate choosing a window solution with the best performance and the lowest environmental impact.

Reference

Kellenberger, D. and Perez, N. December 2008. LCA-based Windows Calculator.Report SM3570/6 for Beacon Pathway Limited.

Disclaimer

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1 Executive Summary

This project is part of the ‘Criteria Development and Embedding System’ phase of work within Beacon’s Systems work stream. The goal of the overall systems strategy is to develop systems that enable a house to perform to the HSS High Standard of Sustainability™ (HSS™) as defined by Beacon [1]. The aim of this research was to provide Beacon with a working prototype of a tool that allows the quantification of (environmental) sustainability on a system level, based on a specific functional unit (a defined window (geometry) with a certain thermal resistance (R-value in W/ m^2°C)) over a lifespan of 50 years. The methodology used to calculate the environmental impact is Life Cycle Assessment as defined in AS/NZS ISO 14040 and 14044 [4] and [5].

This project has resulted in the development of an Excel-based window calculator, offering a simple user interface for the user to define a specific window. Based on the information entered, the calculator will calculate the environmental impact of the window over a specific lifespan, as well as the resulting R-value.

The prototype window calculator aims to provide environmental data that will guide the development of new window systems by:

- quantifying the environmental sustainability of a window;
- identifying the environmental hot spots within the life span of a window;
- comparing different window designs based on a common functional unit.

The system boundary includes the whole life cycle of a window over 50 years, excluding transportation to and from the building site and the construction and demolition work on site.

The functional unit is a defined window (geometry) with a certain thermal resistance (R-value in W/ m^2°C) over an overall life span of 50 years.

The prototype of the window calculator includes the following impact assessment categories:

- Fossil- and nuclear-based Cumulative Energy Demand (CED) [MJ]
- Hydro-based CED [MJ]
- Biomass-, wind-, solar-, and geothermal-based CED [MJ]
- EcoIndicator 99 (H/A) [Points]
- Global Warming Potential (GWP) [CO_2-Equivalent]

Information on the quantity of materials needed to produce the framing and glazing was taken mainly from printed material available from producers or from their websites. The R-values for the windows were taken from a BRANZ publication [12]. Glazing information was taken from the Metro Glasstech Website [www.metroglasstech.co.nz]. The NZ Standard 4214: 2006 provided the formula to calculate the total R-value from the R-value of the window and glazing. The life cycle impact assessment datasets were taken from a Swiss publicly available list

"ecological building material list (version 1.0.2)" [1], which is based on the ecoinvent LCI database. As soon as NZ LCI datasets are available these will be incorporated into the prototype tool and an updated version of the tool sent to Beacon.

The window systems studied in the prototype windows calculator were:

- Single glazed with timber and aluminium frames.
- Double glazed with aluminium, aluminium-timber and PVC-U frames.
- Triple glazed with PVC-U frame.

Each of the categories is analysed with using three different opening methods: casement, horizontal sliding and fixed.

The calculator is structured at four different levels, two of which are background levels which contain the data that drives the prototype calculator, and two levels that the user interfaces with. Briefly, these levels are:

- Background information. Background information came from the Life Cycle Impact Database for the materials and the R-value for the various Frames and Glazing.
- Impacts information. The impacts of the different types of window frames are offered in m and the window glazing in m2, and were derived from [1]
- User Interface. The user interface is the level where the user defines the specific window (geometry of window, type of glazing, frame, opening, etc.).
- Outputs. The output level provides the results calculated by the prototype calculator: a graphical representation of the environmental impacts of the window system and the R-value as a number.

The functionality of the tool and its reporting were demonstrated by analysing two different window design systems. The following points need to be taken into account when interpreting the results:

- Life Cycle Impact datasets were taken from a Swiss/European LCI database
- the disposal datasets represent typical waste disposal scenarios in Switzerland/Europe which do not adequately represent the New Zealand situation
- no paint on wood disposal is included in the LCIA datasets used.

Improving these points and adding cost as a further impact assessment category are part of possible next steps. Applying the same principle to produce an appropriate door, roof and floor calculator would target a whole-house calculator to design and assess a complete building.

[1] ***http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de, in German, access date 31.07.2008***

2 Introduction

2.1 Background

Beacon Pathway is a research consortium, established in May 2004 with the aim of encouraging and improving New Zealand's sustainability in the residential built environment. Its shareholders are leaders in the construction industry, research and local government and include central government through the Foundation for Research Science and Technology.

This project is the part of Beacon's first project "Criteria development and embedding systems" as part of its systems strategy. The goal of the overall systems strategy is to develop systems that enable a house to perform to the HSS High Standard of Sustainability® (HSS®) [1].

In accordance with Beacon's goal of achieving a HSS® in 90% of NZ homes by 2012, Beacon considers the home to be a system and has identified a set of performance benchmarks (the HSS®) to describe its performance. A house is also a collection of systems, e.g., roof, thermal envelope, heating etc. Scion has developed a set of criteria, based on Beacon's definition of HSS® [1]. The criteria were applied in a prioritisation process that identified the systems which, if improved, have the most potential to assist Beacon in achieving its goal of improving the sustainability of new and existing NZ homes [1]. The results of the criteria development project [1], for example, identified that ease of installation is a key criteria for retrofit window solutions.

From the prioritised lists (one for existing homes, the other for new homes) two systems were selected for more detailed research: walls for new homes and windows for existing homes. This report describes the development of an Excel-based calculator for windows for existing homes (reftofit windows). Scion has previously developed a wall calculator, which is available to Beacon for research purposes, so a second calculator was not developed under this project.

In the context of the systems strategy, a 'system' is the smallest part of a building where function (functional unit) can be appropriately prescribed. The function can be one or several relevant properties (e.g., static properties, heat and sound transfer or insulation). Within a certain system with a pre-defined function, different design options with different environmental outcomes can be described and compared. This provides a context for improving the standard of sustainability of the system. For example, a retrofit window system can be defined as a system which improves the sustainability of the window performance, and may include the components of frames, sills, glazing, accessories, shading/shutters, drapes/blinds and pelmets.

For every solution, specific 'designs' can be achieved which comprise a particular set of materials, and components. For example, within the solution of 'double-glazed windows' there are insulated glass units (IGU) with no additional insulating measures, insulated glass units with argon filling or low emissivity (Low E) glass and with argon filling in different frames.

2.2 Project Aim

The aim of the project is to provide Beacon with a working prototype tool that quantifies environmental impacts of windows at a system level, based on a functional unit.

The output of this project is a prototype of an Excel-based window calculator offering a simple GUI for the user to define a specific window. Based on this information, the calculator presents the environmental impacts of the window over a specific lifespan, as well as the resulting R-value. It should be noted that, due to a lack of New Zealand-specific Life Cycle Inventory data, the calculator can at this stage only provide an approximation of the environmental impacts.

Input into the calculator of a range of existing and new window designs will support the process of finding the best window solution for New Zealand houses. Use of the tool will support the determination of the most environmentally sustainable option for the window design. Promoting and using these ‘best-solutions’ will support the process of improving the standard of sustainability for New Zealand houses.

Designers of buildings and building components, i.e. window manufacturers, could also be potential users of a comprehensive window calculator based on the prototype developed in this project.

2.3 Report Structure

Chapter 2.4 of this report provides a short introduction to Life Cycle Assessment (LCA). The remainder of the report is divided into four main parts: The goal and scope of the LCA performed by the calculator, the structure of the calculator, the results, and conclusions/next steps.

2.4 Life Cycle Assessment

Life Cycle Assessment (LCA) is based on the concept of integrating production and consumption strategies over a whole life cycle, thus preventing a piecemeal approach to systems analysis. Life cycle approaches avoid problems moving from one stage of the life cycle to another, from one geographic area to another, and from one environmental medium to another.

LCA is an analytical tool for the systematic evaluation of the environmental impacts of a product or service system through all stages of its life. It extends from extraction and processing of raw materials through to manufacture, delivery, use, and finally to waste management. This is often referred to as ‘cradle to grave’. A number of other environmental assessment tools are restricted to the production process, which is sometimes called ‘gate-to-gate’ or, in the case of embodied energy, cover the life cycle from ‘cradle to gate’, without taking the end of life into account.

In industry, LCA can be used not only for product improvement and product design by identifying environmental hotspots in production processes, but also in upstream or downstream processes such as the type of energy used in the production process and additives used in the product, or in the use phase of a product. LCA results can also be used as part of an environmental management tool to prove continuous improvement or for providing information for eco-labelling or environmental rating schemes.

2.4.1 Definition of Life Cycle Assessment

ISO 14040 defines LCA as [1]

"… a technique for assessing the environmental aspects and potential impacts associated with a product by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout the life of a building (i.e., 'cradle-to-grave') from raw material acquisition, construction, use, and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences".

2.4.2 Elements of a Life Cycle Assessment

An internationally accepted framework for LCA methodology is defined in AS/NZS ISO 14040 and 14044 [4] and [5]. These standards define the generic steps to be taken when undertaking LCA.

2.4.3 Four different phases can be distinguished [5]:

1. ***Goal and Scope Definition:*** The goal and scope of the LCA study are clearly defined in relation to the intended application.

2. ***Inventory Analysis:*** The inventory analysis involves the actual collection of data and calculation procedures. The relevant inputs and outputs of the analysed product system are quantified and produced as a table.

3. ***Impact Assessment:*** The impact assessment translates the results of the inventory analysis into environmental impacts (e.g., global warming potential, ozone depletion). The aim of this phase is to evaluate the significance of potential environmental impacts.

4. ***Interpretation:*** In this phase conclusions and recommendations for decision-makers are drawn from the inventory analysis and the impact assessment.

These can be represented as shown in Figure 1. In practice, LCA involves a series of iterations, as its scope is redefined on the basis of insights gained throughout the study.

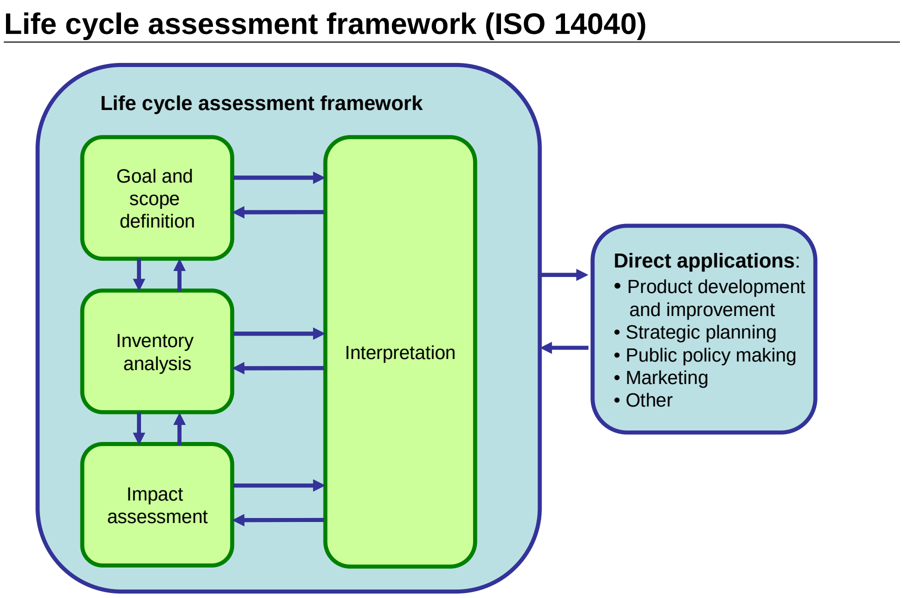


Figure 1: LCA framework (ISO 14040)

3 Goal and Scope

3.1 Introduction

ISO 14040 requires a definition of the goal and scope to provide the necessary information that allows comparisons between window designs with LCA.

3.2 Goal

The prototype window calculator aims to provide environmental data that will guide the development of new window systems by

- quantifying the environmental sustainability of a window;
- identifying the environmental hot spots within the lifespan of a window;
- comparing different window designs based on a common functional unit.

3.3 Scope

3.3.1 System Boundaries

The system boundary used for the calculation of the environmental impact of windows is illustrated in Figure 2.

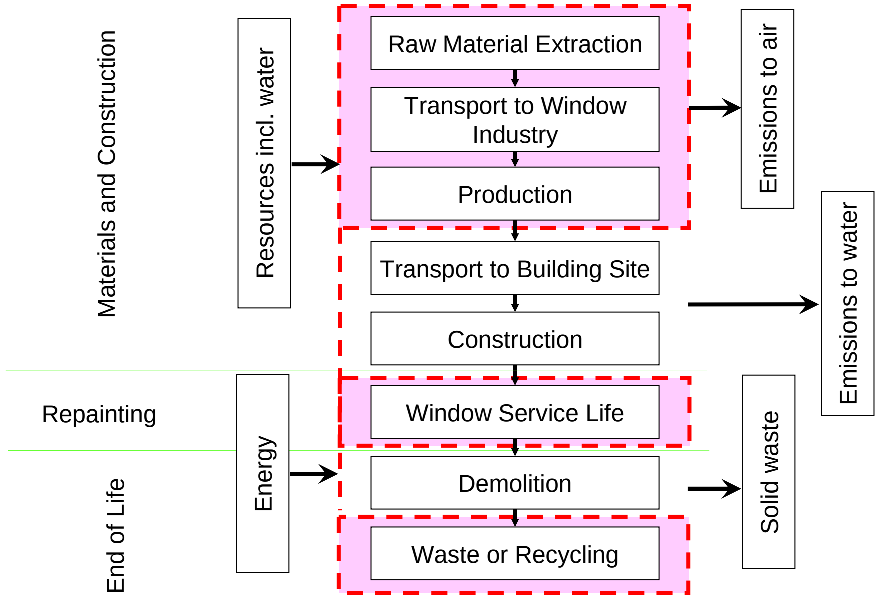


Figure 2: System boundary of the windows (dotted area)

The pink boxes in Figure 2 represent the life phases of a window that are taken into account in the LCA performed by the calculator. The remaining boxes, transportation of the materials to the building site and the construction and demolition processes, have not been taken into account, as it is assumed these processes are similar for all window designs. The window service life includes only the materials which have to be replaced over the whole life cycle (e.g., paint). Additionally, for the amount of materials used, a 10% cutting waste has been added (including its disposal).

3.3.2 Functional Unit

The functional unit is a defined window (geometry) with a certain thermal resistance (R-value in W/ m^2 °C) over a life span of 50 years.

3.3.3 Impact Assessment Categories

The results of a Life Cycle Assessment (LCA) present the environmental impacts of a product over its whole life cycle on the environment through emissions to air, soil and water. In addition to that, energy consumption over the life cycle is taken into account. The results of a LCA therefore relate to key points in the checklist for materials in the HSS™:

- durable and have low maintenance requirements;
- low embodied energy, including minimal impacts due to transport;
- low impact on landfill, or are biodegradable;
- minimal impact on the environment (air, water, land, habitats and wildlife).

The prototype of the window calculator includes the following impact assessment categories. The tool is designed so that the impact categories may be readily changed.

- Fossil- and nuclear-based Cumulative Energy Demand (CED) [MJ].
- Hydro-based CED [MJ].
- Biomass-, wind-, solar-, and geothermal-based CED [MJ].
- EcoIndicator 99 (H/A) [Points].
- Global Warming Potential (GWP) [CO_2-Equivalent].

3.3.3.1 Cumulative Energy Demand (CED)

There are a number of concepts for the characterisation of energy use. “Embodied energy” is probably the most frequently used. However, the definition of the Cumulative Energy Demand (CED) is very comprehensive and widely used in LCA [7]. It is divided into five categories and no aggregated value is presented (Table 1). Common to all categories is the idea that all energy carriers have an intrinsic value. Here, this intrinsic value is determined by the amount of energy withdrawn from nature. However, the intrinsic value of energy resources expressed in MJ equivalents need not be comparable across the sub-categories listed in Table 1. The user may adjust and combine these categories as required for their own calculations (from [8]).

Table 1: Impact assessment method cumulative energy demand (CED) implemented in ecoinvent

	Subcategory	Includes
Non-renewable resources	fossil	hard coal, lignite, crude oil, natural gas, coal mining off-gas, peat
	nuclear	Uranium
Renewable resources	biomass	wood, food products, biomass from agriculture, e.g., straw
	wind, solar, geothermal	wind energy, solar energy (heat and electricity), geothermal energy (shallow (100-300m) geothermic)
	water	run-of-river hydro power, reservoir hydro power

3.3.3.2 EcoIndicator 99 (H/A)

The EcoIndicator 99 impact assessment category is a commonly used methodology for identifying and ranking the overall environmental impacts of a product. It has been developed in the Netherlands for designers and product managers. Pollutants are allocated to impact categories (mid-points) and are normalised by means of division through the national total impact potentials. The environmental effects are then assigned to 'damage categories' (end-points) which include the effects on human health, the quality of an ecosystem, and the fossil and mineral resources[2].

The EcoIndicator 99 method pays special attention to the uncertainties by creating three different perspectives. The uncertainties of ranking the impacts are related to subjective choices in the model. In order to deal with these, three different perspectives of the methodology were developed, using the archetypes specified in Cultural Theory [9]. In this approach we use the approach published in [10].

Table 2 specifies three of the different characteristics of each perspective[3].

Table 2: Three of the characteristics for each perspective

Perspective	Time view	Manageability	Level of evidence
Hierarchist (H/A)	Balance between short and long term	Proper policy can avoid many problems	Inclusion based on consensus
Individualist (I/I)	Short time	Technology can avoid many problems	Only proven effects
Egalitarian (E/E)	Very long term	Problems can lead to catastrophe	All possible effects

[2] *http://www.pe-international.com/standard-navigation/glossary, access date 18.07.2008*
[3] *http://www.pre.nl/eco-indicator99/perspectives.htm, access date 18.07.2008*

3.3.3.3 Global Warming Potential (GWP)

Direct global warming potential (GWPs) of all greenhouse gases are expressed relative to the global warming potential of carbon dioxide. GWPs are an index for estimating the relative global warming contribution due to the atmospheric emission of one kilogram of a particular greenhouse gas, compared to the emission of one kilogram of carbon dioxide [11].

3.3.4 Used Data

3.3.4.1 Quantity of Materials used in the frames and glazing

Information on the quantity of materials needed to produce the framing and glazing was in the main taken from printed material available from producers or from their websites. Where no specific information was available, data was calculated from the extrapolation of existing data based on key assumptions by the researcher.

3.3.4.2 R-values of the frames and glazing

The R-value is a measure of thermal resistance ($K \cdot m^2/W$) used in the building and construction industry; the bigger the number, the better the effectiveness of the building's insulation. R-value is the reciprocal of U-value[4].

The R-values for the windows were from a BRANZ publication [12]. Glazing information was taken from the Metro Glasstech Website[5]. The NZ Standard 4214: 2006 offered the formula to calculate the total R-value from the R-value of the window and glazing.

The used life cycle impact assessment datasets for the materials and for each impact category are described on the next page:

4 *http://en.wikipedia.org/wiki/R-value_(insulation)/, access date 27.07.2008*

5 *http://www.metroglasstech.co.nz/, access date 22.07.2008*

3.3.4.3 Life Cycle Impact Datasets

Table 3 gives an example of the datasets used to calculate the impact of the framing (per m), the glazing (per m^2) and the overall windows.

Table 3: Choice of used Life Cycle Impact Datasets

					cumulative energy demand, fossil & nuclear	cumulative energy demand, water	cumulative energy demand, biomass, wind, solar & geothermal	eco-indicator 99, (H,A), total	IPCC 2001, GWP 100a
Name Window Calculator	**Name (Ecological Building Material List)**	**Default Disposal (not included in impact data)**	**Unit**	**Density [kg/m3]**	**MJ-Eq**	**MJ-Eq**	**MJ-Eq**	**points**	**kg CO2-Eq**
Glazing coated	Glas (Flat-) coated	Final disposal of flat glas	kg	2500	1.44E+01	3.07E-01	3.19E-01	8.92E-02	1.13E+00
Glazing uncoated	Glas (Flat-) uncoated	Final disposal of flat glas	kg	2500	1.24E+01	2.04E-01	2.25E-01	7.72E-02	9.71E-01
Aluminium Spacer	Aluminiumprofil, blank, Primärproduktion (0% Rec.)	Recycling of Aluminium	kg	2700	1.80E+02	4.01E+01	1.53E+00	8.05E-01	1.28E+01
Steel	Steel profile, uncoated, 37% recycling content	Recycling of Steel	kg	7850	2.56E+01	5.58E-01	2.86E-01	1.37E-01	1.41E+00
Hardwood	Sawn timber, hardwood, planed, kiln dried, u=10%, at plant	Final disposal of untreated wood	kg	715	2.53E+00	1.21E-01	1.92E+01	1.00E-01	1.33E-01
PVC	Polyvinylchlorid (PVC) Rohr	Final disposal of PVC	kg	1380	6.50E+01	1.32E+00	8.90E-01	2.47E-01	2.50E+00

The materials listed in the first column represent an example of the datasets used in the calculator. As there is currently no New Zealand database existing, and as most published databases require payment for access to data, a free and publicly available Swiss list “ecological building material list (version 1.0.2)”[6] has been used. This list is based on the ecoinvent LCI database[7]. Each of the datasets has a default disposal scenario. This impact is not listed in the above table and not included in the impact shown in the last five columns, but is included in the final results.

The default disposal scenarios are based on the Swiss situation. Glass, plastic, and timber products are mainly required by law to be incinerated, whereas the metals are mainly recycled.

The calculator has been designed to enable it to be upgraded to accommodate additional impact categories as well as datasets (for example the new New Zealand datasets developed in collaboration between Scion, Victoria University and Stuttgart University, to be published end of 2008).

[6] ***http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de, in German, access date 31.07.2008***

[7] ***www.ecoinvent.ch, LCI database, version 1.3***

3.3.5 Window Systems Studied

The window types included in the calculator were divided into three main groups: single-, double- and triple-glazed. The type and materials of the frame are constrained depending on the glazing that fits into the frame.

The window calculator does not currently contain all the possible framing and glazing options. The choice has been made to include single, double and triple glazing options. For the double glazing, three different, but commonly used, types with the same glass thickness and the same air space have been chosen[8]:

- IGU Clear: insulated glass with no additional insulating measures.
- IGU Argon: insulated glass with argon in the space.
- IGU Low E (Low E #3 & Argon): Use of low emissivity (Low E) glass and filling the space with argon to improve the performance.

Three different framing materials and a number of opening options are included in the calculator in order to give a wide range of scenarios. Although these examples cover only a part of the huge variety of possible options, they are well suited to test the prototype. More research is needed to include all the common existing and possible new window types in New Zealand.

Table 4 describes the frame materials used in the single-, double-, or triple-glazed windows included in the calculator.

Table 4: Windows systems studied

Glass type	Frame material	Method of opening
Single glaze	Timber frame.	Casement Horizontal sliding Fixed
	Aluminium frame	Awning Horizontal sliding Fixed
Double glaze	Aluminium frame	Awning Horizontal sliding Fixed
	Aluminium-timber frame	Awning Horizontal sliding Fixed
	PVC-U frame	Awning Horizontal sliding Fixed
Triple glaze	PVC-U frame	Awning Horizontal sliding Fixed

8 http://www.metroglasstech.co.nz/056.aspx, access date 28.07.08

It can be seen in Table 4 that different frame materials can be used for each type of glazing. The largest variety of materials is for double-glazed windows, where frames can be aluminium, composite aluminium/timber, and PVC-U.

Each type of frame can be classified by their method of opening. The methods for opening included in the prototype calculator are:

- casement or side hung (timber frames);
- awning or top hung (aluminium, aluminium/timber, PVC-U frames);
- horizontal sliding (timber, aluminium, aluminium/timber and PVC-U frames);
- fixed windows (timber, aluminium, aluminium/timber and PVC-U frames);

4 Structure of Prototype Calculator

4.1 Introduction

Figure 3 presents an overview of the structure of the prototype LCA-based window calculator.

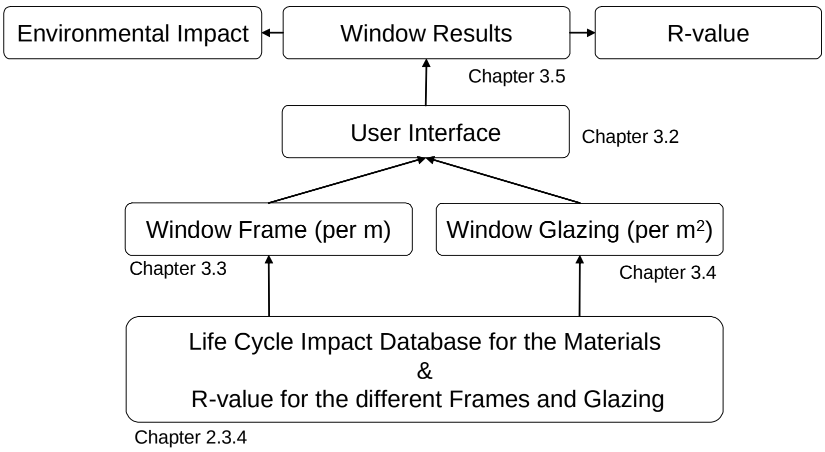


Figure 3: Structure of the window calculator

The current basis of the calculator is a publicly available Impact database for building materials[9]. The framing and glazing types studied includes a full material list connected to the Life Cycle Impact Database, resulting in an impact per linear metre for the frame and per metre squared for the window. Furthermore, each frame and glazing type has an associated R-value. The user interface allows for the definition of a specific window (e.g., size, type of framing, type of glazing, opening/non-opening, etc.). Together with the background information, the impact of the window over the life cycle (currently 50 years) and the total R-value will be generated and displayed.

[9] ***http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de, in German, access date 31.07.2008***

4.2 User Interface

The User Interface includes all the window parameters to be defined by the user. Table 5 gives an overview of the different parameters.

Table 5: Input choice in the user interface

Heighth of window		x	metres
Width of window		x	metres
Type of glazing			Single Double Triple
Type of double glazing			with Air filling with Argon filling with Low E and Argon filling
Framing	single		Wooden frame Aluminium frame
	Double		Aluminium frame Timber-aluminium frame PVC-Steel frame
	Triple		PVC-Steel frame
Opening			Yes No
Way of Opening			Hinge (Awning) Sliding N/A

The first parameters to be defined are the height and width of the wall cavity for fitting the window. The parameters then continue to be defined according to Table 5. As the user continues defining the parameters, the options for each parameter are restricted. For example, if single glazing is chosen, options will be restricted to frames that are allocated to that. Similarly, if an opening window is chosen, the opening method will be required. If a window that can't be opened is chosen, no further options are available.

4.3 Framing

4.3.1 Timber Frame, Single Glazing

Table 6 presents the quantities of framing materials for each of the frame types introduced in chapter 3.3.5 (Windows System Studied). The sources of data (literature) from where material calculations were taken are also presented.

Table 6: Single glazing, timber frame

Method of opening and Material	Quanitity For 1m of vertical part	For 1m of horizontal part	Unit	Literature
Casement				
Hardwood	7.98E+00	9.87E+00	Kg	NZS 3610: 1979
Paint	1.09E-04	2.35E-04	Kg	Timber Windows 2007, BRANZ bulletin, Issue 481.
Horizontal sliding				
Hardwood	7.98E+00	9.87E+00	Kg	NZS 3610: 1979
Paint	1.09E-04	2.35E-04	Kg	Timber Windows 2007, BRANZ bulletin, Issue 481.
Fixed				
Hardwood	7.98E+00	9.87E+00	Kg	NZS 3610: 1979
Paint	1.09E-04	2.35E-04	Kg	Timber Windows 2007, BRANZ bulletin, Issue 481.

Table 6 shows the quantity of materials calculated for the timber frames for single-glazed windows. All three opening methods were assumed to have equal quantities of materials, and are based on a typical casement or side hung (outward opening) timber window. Calculations were made based on the Timber Windows Bulletin from BRANZ published in 2007 [12] and on the New Zealand Standard 3610 [13].

The two materials quantified in the timber-frame, single-glazed option are the timber used in the window components and the paint used to seal the timber. The paint is calculated in kilograms of paint used for a single coat over timber components.

The R-value for the timber frame (single glazing) is 0.39 m^2C/W

4.3.2 Aluminium Frame, Single Glazing

Table 7 represents the materials used for single glazing, with aluminium frame

Table 7: Single glazing, aluminium frame

Method of opening and Material	Quanitity For 1m of vertical part	 For 1m of horizontal part	Unit	Literature
Awning				
Aluminium	2.27E+00	2.27E+00	Kg	Fairview windows and doors. Awning and Casement windows extrusion profiles: F003, F021, 8974.
Rubber	2.44E-02	2.44E-02	Kg	
Horizontal sliding				
Aluminium	3.44E+00	4.88E+00	Kg	Fairview windows and doors. Mainland horizontal sliding windows extrusion profiles: F201, X822, F313, F335, N175, F320, F221, N176.
Rubber	7.31E-02	7.31E-02	Kg	
Woolpile	3.60E-03	3.60E-03	Kg	
Fixed				
Aluminium	1.53E+00	1.53E+00	Kg	Fairview windows and doors. Awning and Casement windows extrusion profiles: F003, 8974.
Rubber	8.52E-02	8.52E-02	Kg	

Table 7 shows the quantity of framing materials calculated for aluminium frames for single-glazed windows. These calculations were based on information from the catalogues of Fairview, who manufactures aluminium windows and doors [14] and [15].

The materials included in this table are aluminium, rubber and woolpile. The aluminium is used in the frame, or fixed component of the windows, and in the sash, or movable, component of the windows. The rubber used for weather seal is also included. In the horizontal sliding windows, woolpile was included as an additional weather seal.

The R-value for the aluminium frame (single glazing) is 0.08 m^2C/W

4.3.3 Aluminium Frame, Double Glazing

Table 8 represents the materials used in double glazing with aluminium frame.

Table 8: Double glazing, aluminium frame

Method of opening and Material	Quanitity For 1m of vertical part	 For 1m of horizontal part	Unit	Literature
Awning				
Aluminium	2.53E+00	2.53E+00	Kg	Fairview windows and doors. Awning and Casement windows extrusion profiles:
Rubber	2.44E-02	2.28E-02	Kg	F003, Z103, K623.
Horizontal sliding				
Aluminium	6.59E+00	3.90E+00	Kg	Fairview windows and doors. Mainland
Rubber	7.31E-02	7.31E-02	Kg	horizontal sliding windows extrusion
Woolpile	3.60E-03	3.60E-03	Kg	profiles: F306, F396, F336, F325, F329.
Fixed				
Aluminium	2.53E+00	2.53E+00	Kg	Fairview windows and doors. Awning and
Rubber	8.52E-02	8.52E-02	Kg	Casement windows extrusion profiles: F003, Z103.

Table 8 shows the quantity of framing materials calculated for aluminium frames for double-glazed windows. As for the aluminium frames for single-glazed windows, calculations in this table were based on information from the catalogues of Fairview, aluminium windows and door manufacturers [14] and [15].

The materials included in this table are aluminium, rubber and woolpile. The aluminium is used in the frame, or fixed component of the windows, and in the sash, or movable, component of the windows. The rubber used for weather seal is also included. In the horizontal sliding windows, woolpile was included as an additional weather seal.

The R-value for the aluminium frame (double glazing) is 0.08 m^2C/W

4.3.4 Aluminium-Timber Frame, Double Glazing

Table 9 represents the materials used in double glazing with an aluminium/timber frame.

Table 9: Double glazing, aluminium/timber frame

Method of opening and Material	Quanitity For 1m of vertical part	For 1m of horizontal part	Unit	Literature
Awning				
Aluminium	3.36E+00	3.36E+00	Kg	Fairview windows and doors. Timberview awning window extrusion profiles: T202, T221S, T238, T211M.
Hardwood	4.96E+00	4.96E+00	Kg	
Paint	6.66E-05	6.66E-05	Kg	
Rubber	1.22E-01	1.22E-01	Kg	
Horizontal sliding				
Aluminium	6.57E+00	6.57E+00	Kg	Fairview windows and doors. Timberview sliding window extrusion profiles: T201, T251, T224S, T238, T471, T401R, T405S, T201, T401, T403S, T224S, T238, T401.
Hardwood	7.01E+00	6.53E+00	Kg	
Paint	1.14E-04	1.09E-04	Kg	
Rubber	2.19E-01	1.40E-01	Kg	
Woolpile	3.60E-03	3.60E-03	Kg	
Fixed				
Aluminium	1.25E+01	1.83E+00	Kg	Fairview windows and doors. Timberview awning window extrusion profiles: T202, T238.
Hardwood	3.32E+00	4.85E-01	Kg	
Paint	2.77E-05	4.06E-05	Kg	
Rubber	8.52E-02	8.52E-02	Kg	

Table 9 gives the quantity of framing materials calculated for an aluminium/timber composite frame for a double-glazed window. Calculations in this table were based on information available from the catalogues of Timberview, aluminium/timber framed windows [16] and [17].

The materials included in this table are aluminium, rubber and woolpile. The aluminium is used in the frame, or fixed component of the windows, and in the sash, or movable, component of the windows. The rubber used for weather seal is also included. In the horizontal sliding windows, woolpile was included as an additional weather seal.

For all timber components, the calculation of kilograms of paint used for a single coat over the timber components is included as an additional material used for maintenance.

The R-value for the aluminium/timber frame (double glazing) is 0.14 m^2C/W

4.3.5 PVC Frame, Double Glazing

Table 10 represents the materials used in double glazing, with PVC frame.

Table 10: Double glazing, PVC-U frame

Method of opening and Material	Quanitity For 1m of vertical part	For 1m of horizontal part	Unit	Literature
Awning				
PVC	3.32E+00	3.32E+00	Kg	Homerit PVC-U Windows and doors technical literature. (2006). Page 15 Tilt and turn window.
Steel	2.37E+00	2.37E+00	Kg	
Rubber	2.92E-01	2.92E-01	Kg	
Horizontal sliding				
PVC	3.93E+00	3.93E+00	Kg	Homerit PVC-U Windows and doors technical literature 2006. Page 18 Tilt and slide window.
Steel	6.42E-01	3.65E+00	Kg	
Rubber	1.46E-01	1.46E-01	Kg	
Woolpile	7.20E-03	7.20E-03	Kg	
Fixed				
PVC	3.32E+00	3.32E+00	Kg	Homerit PVC-U Windows and doors technical literature 2006.
Steel	2.37E+00	2.37E+00	Kg	
Rubber	1.46E-01	1.46E-01	Kg	

Table 10 gives the quantity of framing materials calculated for PVC-U frame for a double-glazed window. Calculations in this table were based on information available in the catalogues of Homerit, PVC-U Windows and doors manufacturer [18].

The materials included in this table are PVC, steel, rubber and woodpile. PVC is used in the frame, or fixed, component of the windows and in the sash, or movable, component of the windows. The steel included in Table 10 works in conjunction with the PVC, helping to structure both the windows frames and sashes. The rubber used for the weather seal of windows is also included and, in the case of horizontal sliding windows, woolpile was included as an additional weather seal.

The R-value for the PVC-U frame (double glazing) is 0.33 m^2C/W

4.3.6 PVC Frame, Triple Glazing

Table 11 represents the materials used in the triple glazing, PVC frame.

Table 11: Triple glazing, PVC-U frame

Method of opening and Material	Quanitity For 1m of vertical part	 For 1m of horizontal part	Unit	Literature
Awning				
PVC	4.97E+00	4.97E+00	Kg	Assumptions made based on PVC-U double glass windows. Homerit PVC-U Windows and doors technical literature 2006.
Steel	3.55E+00	3.55E+00	Kg	
Rubber	2.92E-01	2.92E-01	Kg	
Horizontal sliding				
PVC	5.90E+00	5.90E+00	Kg	Assumptions made based on PVC-U double glass windows. Homerit PVC-U Windows and doors technical literature 2006.
Steel	5.48E+00	5.48E+00	Kg	
Rubber	1.46E-01	1.46E-01	Kg	
Woolpile	7.20E-03	7.20E-03	Kg	
Fixed				
PVC	4.97E+00	4.97E+00	Kg	Assumptions made based on PVC-U double glass windows. Homerit PVC-U Windows and doors technical literature 2006.
Steel	3.55E+00	3.55E+00	Kg	
Rubber	1.46E-01	1.46E-01	Kg	

Table 11 gives the quantity of framing materials calculated for a PVC-U frame for a triple-glazed window. Quantities in this table were assumed based on information available from the catalogues of Homerit, PVC-U window and door manufacturer [18].

The materials included in this table are PVC, steel, rubber and woodpile. PVC is used in the frame or fixed part of the windows and in the sash or movable part of the windows. The steel included in Table 11 works in conjunction with the PVC, helping to structure both the windows frames and sashes. The rubber used for the weather seal of windows is also included and, in the case of horizontal sliding windows, woolpile was included as an additional weather seal.

The R-value for the PVC-U frame (triple glazing) is 0.33 m^2C/W

4.4 Glazing

Table 12 gives an overview of the different glazing types included in the calculator.

Table 12: Description of the glazing types included in the calculator10

Type of glazing	Simple Description	Metro Glasstech description	outer glass	air space	middle glass	air space	inner glass	U-value
			mm	mm	mm	mm	mm	W/m2C
	Single	Single clear	4					0.17
	Double							
	Triple	Triple	4	12	4	12	4	0.56
Type of double glazing	Simple Description	Metro Glasstech description	outer glass	air space	middle glass	air space	inner glass	R-value
			mm	mm	mm	mm	mm	W/m2C
	with Air filling	IGU Clear	4	12	4			0.37
	with Argon filling	IGU Argon	4	12	4			0.38
	with Low E and Argon filling	IGU (Low E #3 & Argon)	4	12	4			0.63

This work concentrates on the methodology of the window calculator and, as such, only a small selection of glazing options has been included, with the intention of having a minimum of one single, one double, and one triple glaze. To demonstrate the potential of the window calculator, the double-glaze option has been subdivided into three double-glaze types.

Based on Table 12 the materials used were calculated and are illustrated in Table 13, per m^2 of glazing.

Table 13: Description of the glazing included in the calculator

(per m2 of glazing)		Type of glazing	Single	Double	Double	Double	Triple
		Type of filling	N/A	with Air filling	with Argon filling	with Low E and Argon filling	N/A
Material	**unit**						
Glazing uncoated	kg		44.5	89.0	89.0	44.5	133.5
Glazing coated	kg					44.5	
Aluminium Spacer	kg			1.9	1.9	1.9	3.8
Primary seal	kg			0.014	0.014	0.014	0.028
Secondary seal	kg			0.702	0.702	0.702	1.404
Moleculare sieve dessicant	kg			0.839	0.839	0.839	1.677
Argon	kg				0.020	0.020	

The calculation of the quantity of glazing material is mainly based on the volumes resulting from Table *12*. All the double- and triple-glaze options are sealed to keep the space gas tight. In this case the spacer (a device which holds the glass in the right distance) is made from aluminium and needs a primary seal to attach it to the glass and a secondary seal to make it airtight. The information for the aluminium spacer is taken from a Swiss study [19] and illustrated in simplified form in Figure 4.

[10] ***http://www.metroglasstech.co.nz/056.aspx and http://www.metroglasstech.co.nz/094.aspx, access date 28.07.2008***

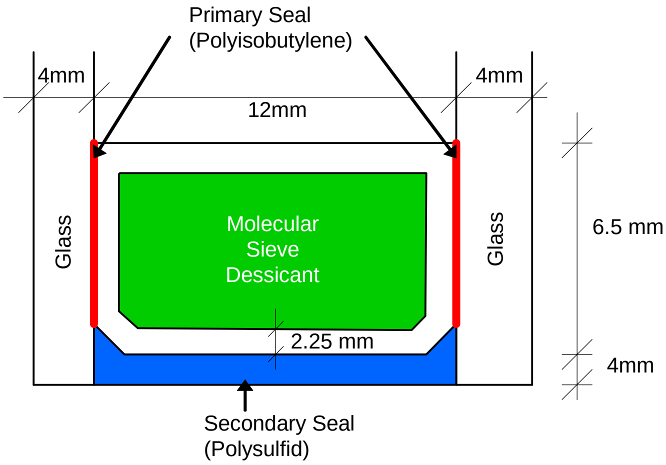


Figure 4: Aluminium Spacer

The aluminium spacer has roughly the geometry of 12mm * 6.5mm and a thickness of 2.25 mm. It is filled with molecular sieve desiccant and has a primary seal made from polyisobutylene and a secondary seal made from polysulfide.

4.5 Results

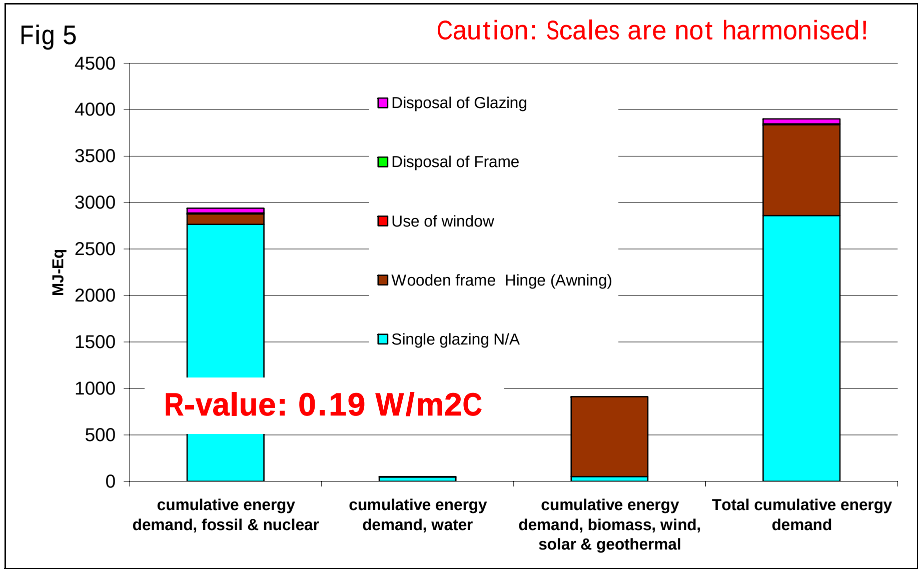
4.5.1 Introduction

To illustrate the scope of the results that can be obtained from the prototype LCA-based window calculator, the environmental impacts of two different window designs have been calculated. The two window designs are:

- A single-glazed, timber-frame, top hung (awning) window with a size of 2 * 2.5m and an R-value of 0.19 W/m^{2}C (very low insulating).
- A double-glazed with Low E and Argon filling, PVC frame, top hung (awning) window measuring 2 * 2.5m and a R-value of 0.53 W/m^{2}C (very high insulating).

As the two windows have very different thermal performances ***they should not be compared***. Therefore there was no need to harmonise the scales of the figures but rather concentrate on good readability.

4.5.2 Cumulative Energy Demand [MJ]



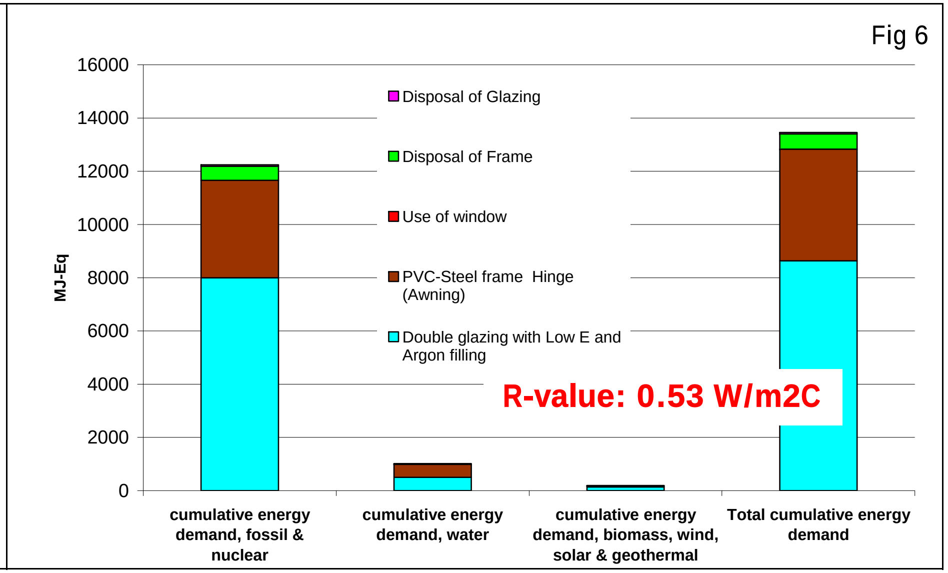


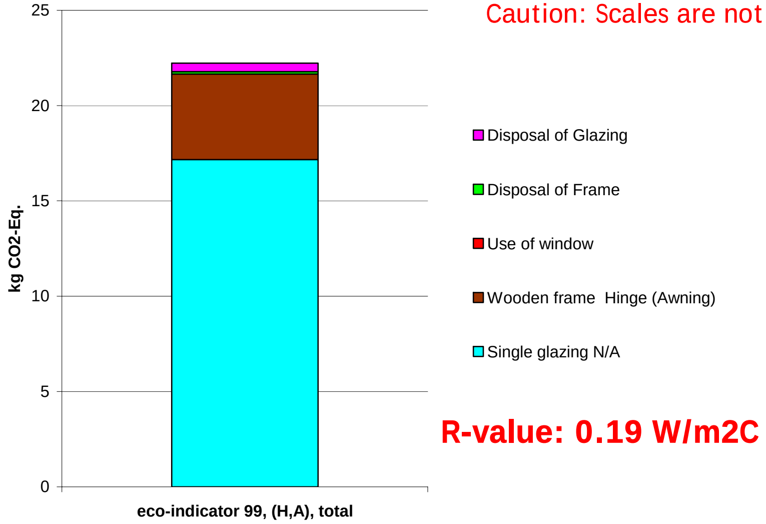
Figure 5: CED for a single glazing, timber frame

Figure 6: CED for double glazing with Low E and Argon filling, PVC frame

Both window types are dominated by the glazing, independent of the degree of glazing. The single-glazed, timber-framed window makes a large contribution to the embodied energy in the category CED biomass, wind, solar and geothermal. This is primarily due to the energy stored in the biomass. In this case the disposal of the frame does not include any energy recovery. If there is energy recovery there would be no embodied energy in the biomass, as the energy would be allocated to the energy. The PVC/steel frame has a relatively high impact due to the production of the steel components.

4.5.3 Total EcoIndicator 99 (H/A) [Points]

Fig 7



Caution: Scales are not harmonised!

Fig 8

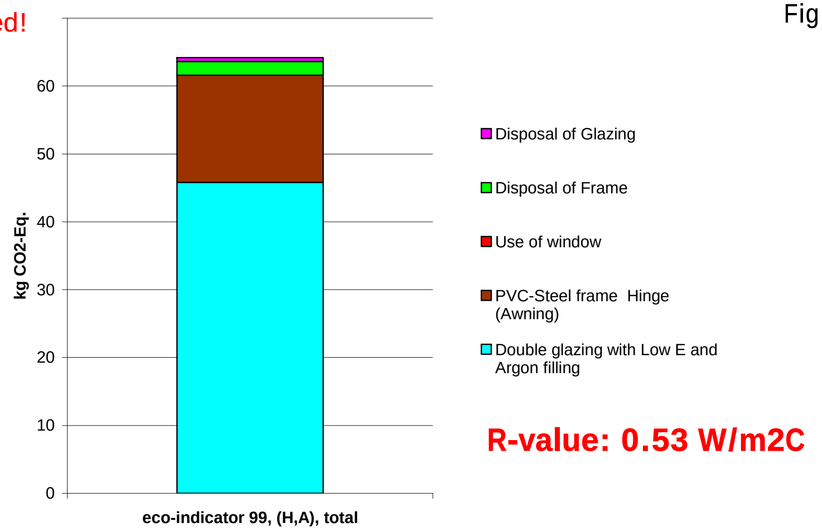
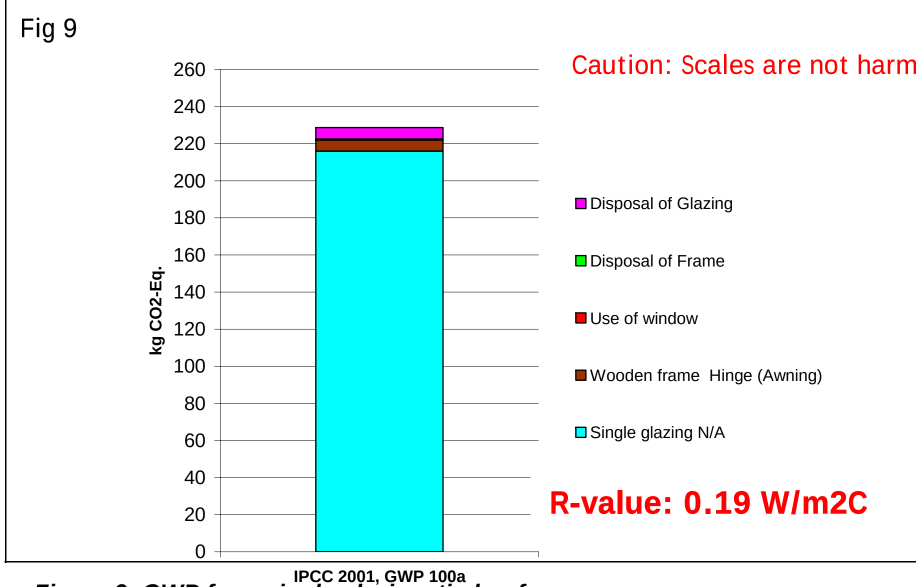


Figure 7: EI99 (H/A) for a single glazing, timber frame

Figure 8:EI99 (H/A) for double glazing with low E and argon filling, PVC frame

The total impact represented by the EcoIndicator 99 (H/A) of both windows is dominated by the glazing. The use phase of the timber frame includes one repainting over 50 years, which is not visible in the total result.

4.5.4 Global Warming Potential [kg CO2-Eq.]



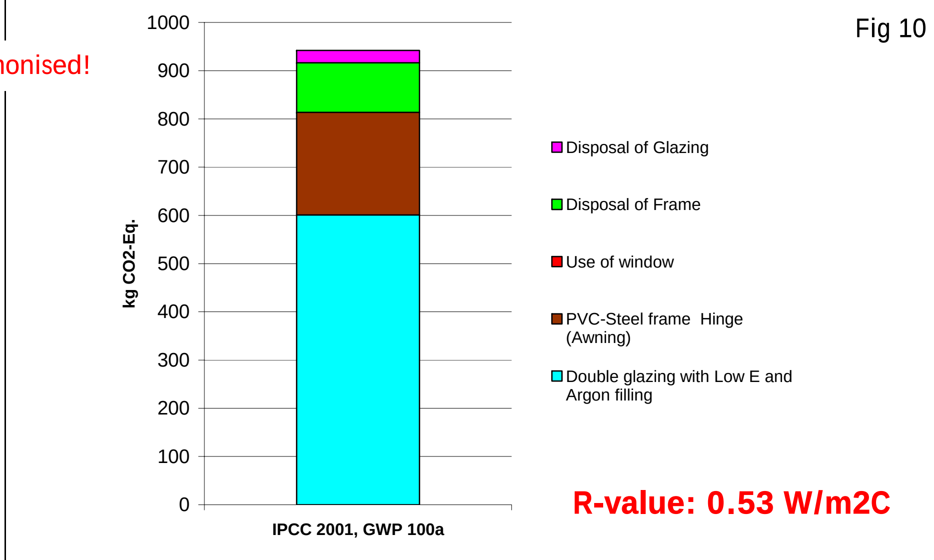


Figure 9: GWP for a single glazing, timber frame

Figure 10: GWP for double glazing with Low E and Argon filling, PVC frame

When considering Global Warming Potential (kg CO_2-Eq.), the result looks quite different. For the single-glazed, timber-frame window the impact of the glazing is clearly dominating the total impact. The low GWP from the timber frame is due to the fact that the disposal is based on European data and is therefore incinerated. The incineration process releases all of the stored CO_2 and therefore has about the same impact as the frame production. The production of PVC/steel frames and double glazing have a reasonably high impact due to the processes which are partly fossil-fuel driven (steel and PVC production, glass melting)

5 Conclusions

The key feature of the prototype calculation tool is that it is based on an actual window design, including the geometry, the type of glazing and framing, as well as the method of opening. The tool offers the ability to readily calculate the overall quantity of materials in the window and to study the effect of window sizes on the environmental impact in relation to the other parameters (glazing and framing type as well as opening type).

The prototype of the window calculator has been developed to show the full potential of the tool when it has been populated with a wider range of possible framing and glazing options in New Zealand. The complete version will allow an assessment of existing windows and will inform the design process of new, more environmentally sustainable solutions within a building.

It is proposed that the main user of the tool will be Beacon, who could continue the research to a point where recommendations on design options are possible. A further target user of the comprehensive tool would be the designer of a building, component and/or window (architects, builder and industry). As the tool is very detailed and transparent it could also be used by educational institutions (e.g., Universities, Unitecs, etc.) to teach students the correlation of decisions and the environmental impacts.

It is not possible to compare various window designs with the same thermal resistance using the existing Excel-based prototype as it does not yet offer a reverse calculation starting with the definition of the R-value to come up with a choice of possible comparable solutions. This is a potential next step listed in Chapter 6. Experiences with the wall calculator indicated more work is needed to enable the reverse function. This function will allow entering a specific R-value whereas the tool potentially shows lots of different window design solutions fulfilling that thermal requirement, depending on the number of offered glazing and framing types (incl. glazing thickness, space, etc.). To enable a useful reverse function, more research is needed.

The potential of the tool was demonstrated by analysing the design of two different window types and showing within this report, the results the prototype calculator gave for each window type. The full strength and potential of the tool will be demonstrated with the inclusion of further window designs.

The LCA model, including the Life Cycle Impact datasets used for the two window systems, includes the solar energy (biomass energy) uptake for growing the wood. This leads to a relatively high CED result for the timber frame. If the energy at the end of life is recovered rather than wasted the utilised energy would be credited towards the product (e.g., vapour, electricity, etc.) and the overall CED result for the window would change. This shows how the model could be extended with regard to optimising the whole supply chain for wooden construction materials.

Several factors need to be taken into account when interpreting the results:

1. The Life Cycle Impact datasets have been taken from a Swiss/European LCI database. This is mainly because it is worldwide one of the largest, most comprehensive, and transparent LCI databases. To improve the results, the NZ Life Cycle Impact datasets currently under development will be added and a new updated prototype delivered to Beacon.
2. The disposal datasets represent typical waste disposal scenarios in Switzerland/Europe, which do not adequately represent the New Zealand situation. This would require an extension of disposal scenarios for New Zealand Landfills. A significant impact category would be long-term emissions, which would mainly affect soil and water.
3. As stated in the report, no paint on wood disposal is included in the LCIA datasets used. This should be added as soon as possible. However, the assessment of the impacts of painted timber in landfills is difficult.

Currently the tool is a prototype tool which the project team can use for Part B of Phase one of the systems project. Depending on how Part B is scoped, it may be necessary to include further design options within the prototype. Further work is required if the tool is to be used outside of the project group. Populating the tool with the most widely used window systems will enable the assessment of the environmental sustainability of different solutions as part of the QFD matrix. Nevertheless this prototype showed the huge variety of possible applications.

6 Next Steps

Potential steps to improve the calculator include:

1. Adding more NZ-typical glazing and framing options in order to make recommendations on which windows have a high R-value and a low environmental impact.
2. Replacing the Life Cycle Impact datasets with New Zealand datasets.
3. Including different New Zealand disposal scenarios and associated datasets.
4. Including a dataset on the disposal of painted timber in a New Zealand landfill.
5. Adding cost as a further impact assessment category.
6. Apply the same principle to produce an appropriate door, roof and floor calculator.

The grouping of the system calculators for all housing systems could produce a user-friendly and unique LCA-based building assessment tool. This tool would be built from all the independent system calculators, e.g., wall, floor, roof, windows/doors, and could in future be extended to include access roads, transportation, indoor climate, land use, etc. This would support the process in finding the hot spots from the activity “living”.

7 References

[1] Easton, Lois (November 2006), PR109 *Defining the Benchmarks for Beacon's High Standard of Sustainability*, prepared for Beacon Pathway Limited.

[2] Bayne. K. M.; Allan, T.; Baker, K. July 2008. Design Criteria for Retrofit Windows and Walls for New built. Report for Beacon Pathway Limited.

[3] Nebel, B., Bayne, K. M., Crookshanks, C. August 2008. Prioritisation of building systems. Working paper for Beacon Pathway Limited.

[4] International standardisation organisation 2006. Environmental Management - Life cycle assessment - Principles and Framework. ISO 14040.

[5] International standardisation organisation 2006. Environmental Management - Life cycle assessment – Requirements and Guidelines. ISO 14044.

[6] Guinée, J. (ed.). 2002. Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht

[7] Frischknect R, Heijungs R, Hofstetter P. 1998. Einstein's Lessons for Energy Accounting in LCA, Int. J. LCA 3 (5) 266 – 272 (1998)

[8] Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Dones R, Hellweg S, Hischier R, Humbert S, Margni M, Nemecek T, Spielmann M (2004): Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000 No. 3, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland

[9] Thompson M., Ellis R., Wildavsky A. 1990. Cultural Theory. Westview Print, Boulder USA.

[10] Hofstetter, P. 1998 Perspectives in Life Cycle Impact Assessment; A Structured Approach to Combine Models of the Technosphere, Ecosphere and Valuesphere, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1998. See www.springeronline.com

[11] IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment, Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

[12] Building Research Association of New Zealand 2007. Timber windows. Porirua City, N.Z.: BRANZ.

[13] Standards Association of New Zealand 1979. Specification for profiles of mouldings and joinery. New Zealand standard, no. 3610:1979. Wellington, NZ: Standards Association of New Zealand.

[14] Fairview windows and frames 2006. Awning and Casement windows extrusion profiles (Catalogue).

[15] Fairview windows and frames 2006. Mainland horizontal sliding windows extrusion profiles. (Catalogue).

[16] Fairview windows and frames 2006. Timberview awning window extrusion profiles. (Catalogue).

[17] Fairview windows and frames 2006. Timberview sliding window extrusion profiles. (Catalogue).

[18] Homerit 2006. PVC-U Windows and doors technical literature 2006. (Catalogue).

[19] Classen M., Kellenberger D. 2006. Oekologische Bilanzierung von *** (company name) Fenster (confidential), EMPA, Duebendorf, Switzerland, 2006.