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Technical Evaluation of Environmental Assessment Rating Tools

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Technical Evaluation of Environmental Assessment Rating Tools

Prepared for the

Forest & Wood Products
Research & Development Corporation

by

S. Seo, S. Tucker, M. Ambrose, P. Mitchell and C-H. Wang

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Background

Evaluation tools for assessing environmental performance of buildings have been developed and used in practice in many countries including Australia. The number and diversity of tools make it difficult for designers to identify the appropriate tools or information needed for their particular purpose.

The evaluation tools include quantitative impact assessment tools for selection of materials and technologies, and analysis and simulation tools for calculating (predicting) energy consumption, lighting and indoor environmental quality. These tools are used in the preliminary design stages and in the whole building performance evaluation process.

Objective

The main focus of the study was to investigate the environmental impact assessment of building products, especially in relation to wood products, as incorporated in existing tools, to identify a comprehensive set of environmental attributes and to recommend what information is required to accurately reflect the benefits of Australian wood based products in the tools which are being adopted in Australia.

Building/building product evaluation tools

A total of 27 building evaluation tools in use around the world and in Australia were reviewed with particular attention to building material inclusion**.**

The project found that:

- Most tools cover the building level, based on some form of life cycle assessment database except for Ecospecifier and Evergen in Australian tools and BEES and Ecoquantum for non-Australian tools, which are focused on building products.
- About one third of the tools can be categorised as **assessment** tools which provide quantitative performance indicators to help make decisions on design alternatives while the other two thirds of the tools are **ratings** tools which determine the performance level of a building, against agreed (often subjective) standards, often measured in stars.
- Several tools are restricted to emphasizing energy efficiency relating only to heating and cooling (NatHERS, AccuRate, BERS, and Firstrate) and energy consumption during operation of a building (ABGR).
- Since most assessment and rating schemes are based on overall performance, any differences in manufacturing the materials used do not affect the decisions and the schemes are almost entirely unable to differentiate between choices of materials except for indirect consequences.
- Four of the Australian tools cover the full life cycle of the whole building (EPGB, LCAid, LCADesign and LISA), seven non-Australian tools (GBTool, BREEAM, LEED, CASBEE, Ecoprofile, GreenCalc, and EQUER).
- In Australia, most tools are used on a voluntary basis except for BASIX in NSW, NatHERS and FirstRate in VIC, and NatHERS in the ACT.
- The most optimistic influence on indicators which can be achieved by choice of materials, both directly and indirectly, across all evaluation schemes was a maximum of about ten percent of the total measures with direct measures at a maximum, contributing a few percent to the total.

- Very few of the existing tools have direct indicators related to wood other than wood from managed certified forests while ignoring advantages of wood such as being renewable, having lower impact on the environment in terms of embodied energy, having lower impact on the environment in terms of air and water pollution, ease of disposal of waste/recyclability, and carbon storage in long life wood structures.
- Operating energy prediction tools addressing energy efficiency in the form of 'thermal comfort' (regulatory tools such as AccurRate, BERS and Firstrate) have a very narrow focus for determining the environmental impact of buildings and ignore any positive impact (operating energy) in relation to capital energy of alternative materials.
- Greater effort should be made to have the environmentally beneficial and whole of life characteristics of the materials used in buildings included directly in the assessment and rating schemes used to evaluate the environmental performance of buildings.
- Even where indicators that are considered indirectly relevant to wood, are included, they could be as relevant to the choice of non-wood related materials and products as they are to wood.
- Some tools based on the life cycle of buildings, such as LISA and LCADesign, show a better case for wood as the materials of choice on environmental grounds, but they do not address all benefits of materials such as wood.

Environmental impact attributes

Consideration of building material issues when material choices are being made identified the extent of required environmental impact attributes. Evaluation of the methodology of the tools exposed the lack of comprehensive requirements in terms of indicators relating to building materials.

Current tools mainly assess building performance with little recourse to material indicators. Direct measures were found to be almost non-existent in the evaluation tools. It follows that, for those issues of relevance specifically to the forest industry, most of the tools had no direct indicators.

Few tools related to wood, or more specifically, few tools reflected the issues of wood products better than other tools. The main issue addressed in relation to wood products referred to resources from a managed forest.

The choice of materials, including wood, has little or no influence on whether a building is classed as green or sustainable in the limited number of tools tested on an example home and alternatives used to assess the impact of different material choices. This lack of inclusion of indicators reflecting environmental advantages or disadvantages of different building material options means specifiers have little reason for choosing wood over alternative products.

The required information needed to reflect the environmental benefits of wood products clearly showed the need for further development of assessment methods for building materials, wood in particular. The current building assessment schemes do little to enhance the use of wood in buildings, despite the environmental advantages of wood products from well managed forests.

There is a lack of adequate information relating to wood derived building products that can currently be incorporated in building evaluation tools, which may be part of the explanation as to why more relevant indicators are not included. There is little verified life cycle information available on forest and wood products, and Life Cycle Inventory (LCI) information for wood products is the least well defined in any current Australian LCI database.

Thus, wood products are at a distinct disadvantage compared to other products, such as steel and concrete, as there is no detailed database to provide strategic insight for use in pro-active environmental marketing, process improvement, comparison for product substitution, and, importantly, to be used to supply information for building evaluation tools. Building designers and material specifiers currently do not have the necessary quality and substantiated information to determine when wood is a superior or competitive choice.

Recommendations for Australian wood products

The forest products industry would benefit through a more advanced life cycle understanding of its products and processes. Life Cycle Assessment (LCA) (according to the International Standards Organisation Environmental Management System 14000 series standards, ISO: EMS 14000 which is a rigorous, well accepted and adopted model) for example, would provide information on the entire product process from forests to disposal, including issues of maintenance, durability, product life, re-use and recyclability.

It is this information which can provide a quantitative basis for comparing wood products, their manufacturing processes and, most importantly from the forest industry point of view, wood products performance against competitors who use other resources to create alternative products. Specifically, the information would provide the forest and wood products industry with the capabilities to:

- Use process oriented environmental assessment to improve the environmental impact of products and processes;
- Market products vis-a-vis competing products, using environmentally sound supply chain information based on a rigorous nationally accepted database; and
- Disseminate supply chain environmental profile information to product users, in particular to environmental building evaluation tools, via plug-ins.

Collection, enhancement and verification of data would provide the industry with credible environmental impact information to improve their environmental bottom line as well as providing data for assessing choice in building products on the basis of environmental impacts. The future potential in obtaining this information for the forest and wood products industry would mean greater acceptance of wood as an environmental material choice, give wood products a greater prominence in evaluation tools, and greater understanding by the industry of future growth areas, such as recycling opportunities, service provision potential, and take back schemes, which would greatly add to the bottom-line in the future market place.

Detailed knowledge of the environmental impacts of wood products also would provide the data for revising the tools to include more measures related to directly to the choice of material.

Most tools are developed for use of building designers/developers to assess their use of building or building materials and they are, at best, only marginally relevant to manufacturers/suppliers of building materials.

There is an increasing inclusion of issues that are not material specific (eg. Waste management, location with respect to transport) in the assessment and rating tool indicators which indirectly affect the use of wood products through materials choices. This suggests that the wood industry should establish partnership approaches with other materials suppliers to clarify performance-based building issues relating to materials.

More detailed knowledge of the environmental impacts of wood products would provide the evidence for revising the tools to include more measures related directly to the choice of material particularly in relation to wood.

INTRODUCTION

The building industry is not only one of the largest industries in most countries of the world, but it is inherently one with the greatest impact on the environment. The increasing awareness of the environment has contributed to concerns regarding the materials used in the buildings in which we live and work. Buildings should exist to provide clean, safe and healthy environments in which the occupants can live, work and enjoy themselves – but this is not always the case.

Sustainable buildings require design professionals to be proficient with building systems interactions and to consider environmental impacts of design decisions. Since environmental issues from buildings are increasing, the green building concept is demanding more attention and everyone needs ideas to lessen the environmental impact of new construction or facility redesign; whether they are architects or engineers, builders or building owners, government officials or decision-makers. Once a building developer or design team sets a project goal to develop a sustainable building or achieve a certain level of green building rating, an integrated design approach is required from the earliest stages of the project to identify design strategies, to select materials and technologies and to evaluate whole building energy and environmental performance (Lewis, 2004).

A number of evaluation tools for buildings have already been developed and used in practice in many countries including Australia. The number and diversity of tools make it difficult for designers to identify the appropriate tools or information needed for their intended purpose.

The evaluation tools include quantitative impact assessment tools for selection of materials and technologies, and analysis and simulation tools for calculating (predicting) energy consumption, lighting and indoor environmental quality. These tools are used in the preliminary design stages and in the whole building performance evaluation process.

This report contains links to many of the tools publicly available for the sustainable design, construction, operation and maintenance of commercial and institutional buildings. Sustainable building strategies are most effective when they are integrated from the very beginning of a project, but the resources listed here can be useful at any point in the building process.

This report comprises:

- A review/evaluation of the existing building and product assessment/rating tools,
- An investigation of a comprehensive set of the environmental indicators in the assessment/rating tools, and
- An identification of the information required for environmental assessment of Australian wood products.

EXISTING EVALUATION TOOLS FOR BUILDINGS AND BUILDING PRODUCTS

As reported recently in Oslo (Danish Building and Urban Research, 2003) there is an internationally growing awareness of building environmental assessment. The International Standards Organisation (ISO) (ISO, 2002a) has been attempting to classify the various approaches adopted. Furthermore, each of the individual evaluation schemes address different aspects of a building's environmental impacts from materials used to a whole of life cycle approach. Their coverage also varies from building components to whole of building construction as illustrated in Figure 1 for Australian tools and rating schemes.

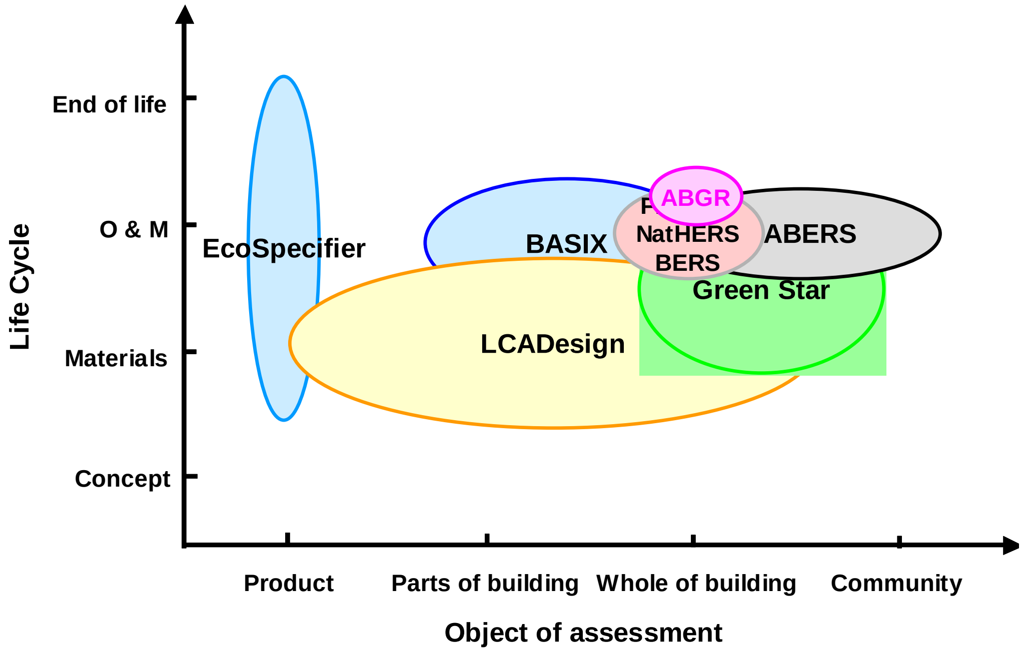

Figure 1 Classification of Australian tools and rating schemes for environmental assessment of buildings and related components

A number of tools exist to evaluate buildings or building products. These tools are summarized here in terms of categories such as scope, target, level, building type applied etc.

Australian tools for buildings and building products

ABGR

The ABGR (Australian Building Greenhouse Rating) Scheme (2005), developed by the Department of Commerce NSW, is a performance based accredited assessment of the greenhouse gas intensity of the operation of office buildings, expressed by awarding a star rating on a scale of one to five. A building with a high star rating will be more energy efficient and cheaper to run, and will result in lower greenhouse gas emissions. Three stars represent current market practice.

The scheme provides a national approach to benchmarking the greenhouse performance of buildings and tenancies. A higher star rated building is expected to be attractive to tenants and investors due to its lower operating costs and its enhanced greenhouse gas performance.

Using 12 months of energy consumption (from bills) and some other details such as the number of people, number of computers, net lettable area and the hours of occupancy, building owners, tenants or managers can obtain a star rating that indicates the greenhouse performance of their office building (Figure 2).

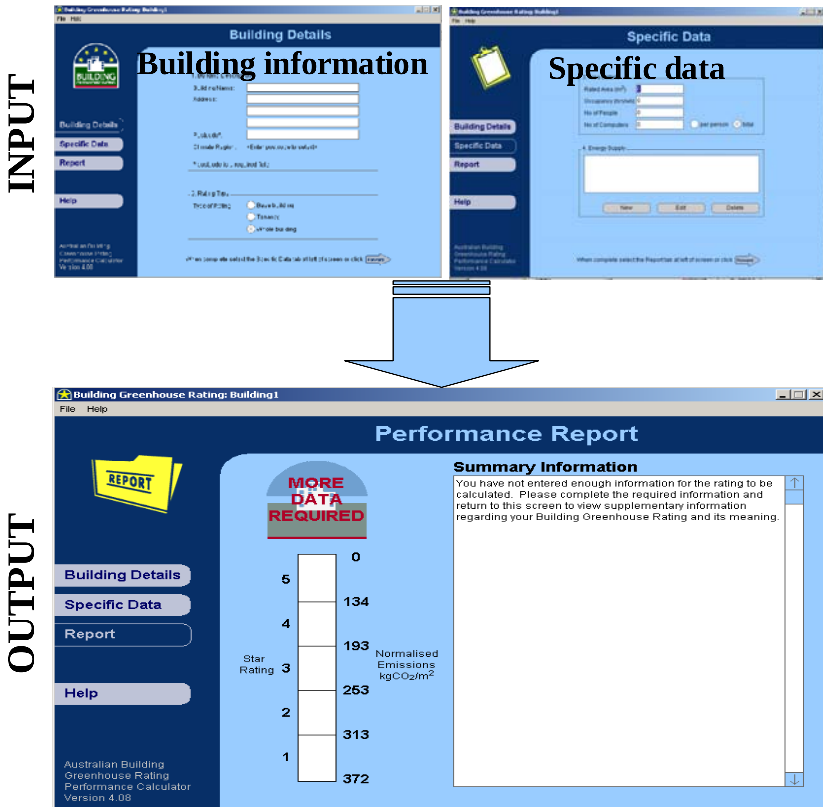

Figure 2 Schematic input/output for the ABGR rating tool

AccuRate

AccuRate is the new version of NatHERS (Delsante, 2005). AccuRate addresses the problems associated with rating homes in tropical and sub-tropical environments through the inclusion of a ventilation model. AccuRate provides a completely new user interface and an enhanced simulation engine. It includes an extensive database of materials, and allows the user to modify the basic wall, floor and other construction elements, or create completely new ones. It can implement more than 20 separately heated/cooled zones, and any number of roof spaces and sub-floor spaces, which are user-definable. Ventilation rate calculations have been greatly improved to enable user specification of sizes and location of openings to outdoors and between rooms. It can calculate flow rates through each opening and account for outside wind speed and direction, indoor air speed and humidity, the effect of flow rate on room temperature, and the effect of air speed on comfort.

AccuRate is still under development and when released, AccuRate will replace NatHERS (see below).

BASIX

BASIX (Building and Sustainability Index) (2005) is a web-based planning tool for local government and proponents of residential dwellings to assess the potential performance of their development against an agreed set of sustainability indices. BASIX is an initiative of the Department of Infrastructure, Planning and Natural Resources, NSW. BASIX provides a comprehensive assessment of how a proposed development will perform against defined sustainability indicators, minimizing the need for the labour intensive assessment of individual proposals.

- BASIX applied in full will address the sustainability indices for water, storm water, energy, indoor amenity, landscape, waste, materials, transport and social.

The first stage of BASIX focuses on water, storm water, energy and indoor amenity. BASIX ensures each dwelling design meets the NSW Government's targets of a 40% reduction in water consumption and a 25% reduction in greenhouse gas emissions, compared with the average home. The greenhouse target will increase to a 40% reduction from July 2006.

BASIX became a mandatory part of the development approval process for all new residential developments from 1st July 2004 in the Sydney metropolitan area, and from 1st July 2005 across the remainder of NSW.

BERS

BERS (Building Energy Rating Scheme) is a computer program which simulates and analyses the monthly, seasonal or annual thermal performance of Australian houses in climates ranging from alpine to tropical (Solar Logic 2005).

BERS allows fast and accurate data entry, and reasonable simulation speeds. It can be used to quickly rate the thermal performance of a building, making the widespread evaluation of houses practical. BERS is a simulation tool for providing thermal ratings as well as being a design tool which can be used to optimise the thermal performance of dwellings.

Houses can be simulated as being conditioned or with no heating or cooling. BERS incorporates the simulation engine, CHENATH, under licence to the CSIRO, and uses hourly climatic data originally collected by the Bureau of Meteorology. Calculated data is displayed in graphic form as well as being written to files. These files can be printed, or imported into spreadsheets, (for further processing), or moved into reports generated by word processors or desktop publishers.

The BERS Star Rating of a building reflects its predicted thermal performance within a specific climate type for a standard set of user behaviour patterns. In regions where buildings may be both heated and cooled, the rating reflects the sum of the heating and cooling energy required to maintain certain zones in the building within a comfort temperature band. This is expressed in terms of annual heating and cooling energy per square metre of conditioned floor area, (MJ/m^2).

Ecospecifier

Ecospecifier is not a tool but a guide to eco-preferable products and materials for the construction industry. It contains a database of hundreds of independently vetted eco-preferable products which have been measured against 30 common industry categories and 130 sub categories (Ecospecifier, 2005).

It purports to help builders and others in the construction industry to better understand what is and what is not a green building product. The information offered by Ecospecifier can be divided into two parts, eco-products and eco-knowledge. Eco-products feature a database of hundreds of eco-preferable products and materials including product descriptions, images etc. Eco-Knowledge is environmental and health priorities for common applications i.e. paint, floors, adhesives etc.

Ecospecifier gives qualitative information on products under the following criteria: energy and greenhouse, habitat and land, resource, human health, and pollution. This kind of information gives tentative guidance to users to simply answer their curiosity as to “which material or product is good or bad for the environment?” But there is no advice or hints on how to reduce environmental emissions or improve resource efficiency. Thus, it might not be sufficient for users who want to use quantitative information as a numerical value in a particular situation.

EPGB

The Environmental Performance Guide for Building (EPGB) scheme is an environmental performance guide for NSW Government Buildings developed by the Policy Services Division of the NSW Department of Public Works and Services (NSW Department of Commerce, 2003). It is structured through a framework of environmental performance categories, suggested strategies, and references to external guides. Issues in this framework are divided into five distinct Environmental Areas that collectively describe the scope of environmental issues for high environmental performance buildings:

- R Resource consumption (energy, land, water, materials),
- E Environmental loadings (greenhouse gasses, ozone depleting substances, site ecology, solid wastes, liquid effluent, physical impacts),
- Q Quality of internal environment (air quality and ventilation, thermal comfort, lighting, noise, materials hazards),
- F Functionality (Adaptability and flexibility, Maintenance of performance, Controllability of systems), and
- M Wider planning issues (economics, management process, commuter transport, cultural environment).

Conceptually, it is useful to consider the resource consumption and loadings as the environmental cost of providing "services" such as human health and comfort and other amenities such as adaptability, and controllability. Wider planning issues addresses issues that either influence the delivery of environmental performance or that represent broader, but critical environmental issues associated with buildings.

All environmental areas are divided into performance categories representing detailed environmental performance for construction. These performance categories remain valid across a broad range of building types with variations on a specific project basis.

Buildings are rated on the issues above and results are shown in two ways (bar charts and single indicator percentage number). The bar charts show assessment scores for each of the environmental issue areas (with internal weighting of relative importance between performance categories). A single Indicator percentage number shows an indicator for the total performance across all framework issues (which is weighted for relative performance between the environmental issue areas).

Evergen

Evergen, a consortium collaboration between industry, government, CSIRO and other R&D providers, seeks to encourage innovation in the construction industry (CSIRO, 2003). Evergen was an idea with a tangible outcome - commercial buildings, which are built faster, perform better, sell for more, and ultimately are recyclable and have a zero net cost to the environment. Evergen was designed to provide the framework, process and tools needed to make optimized decisions to meet triple bottom line performance outcomes.

Criteria covered by Evergen include energy, water, waste, and indoor environment quality for whole building performance.

FirstRate

The FirstRate house energy rating software is a design tool which takes the guesswork out of energy efficient design (Sustainable Energy Australia, 2002). It enables the user to evaluate the energy performance of each part of a house and, by testing the effects of design changes instantly, makes it simpler to design for energy efficiency.

The house energy rating measures the energy efficiency of a house by allocating a point score for various design features (such as building fabric, window design, insulation, orientation and other features) and provides an overall rating on a scale from 0 to 5 stars, with half star increments. An energy efficient house rates 4 stars or higher.

The house energy rating is independent of the size and type of housing. This means that both large and small houses, attached and detached dwellings each have the potential to achieve a good energy efficiency rating.

The FirstRate house energy rating software was developed by correlating the energy use predictions of the CSIRO's Nationwide House Energy Rating Software (NatHERS) with building element properties. FirstRate is based on the results of around 55,000 simulations in each Australian climate zone.

GreenStar

GreenStar, which was developed by the Green Building Council of Australia (GBCA, 2005), is Australia's first comprehensive method for evaluating the environmental performance of Australian buildings based on a number of categories under which specific key criteria are grouped and assessed. These categories include management, indoor environment quality, energy, transport, water, materials, land use, site selection and ecology and emissions.

GreenStar currently focuses on commercial office buildings. As shown in Figure 3, it functions as an accreditation system, increasing the requirements that need to be met in order to gain credits, defining the grey area of 'sustainability'. Within each category the credits awarded have an effective weighting by virtue of the number of credits awarded versus the total credits available. The credits available correlate with, but are not always linearly proportional to, the environmental impact. The GreenStar rating system uses a maximum of six stars to measure performance, as follows:

- Four stars recognizes and rewards best practice in building environmental initiatives;
- Five stars recognizes and rewards Australian excellence; and
- Six stars recognize and rewards international leadership.

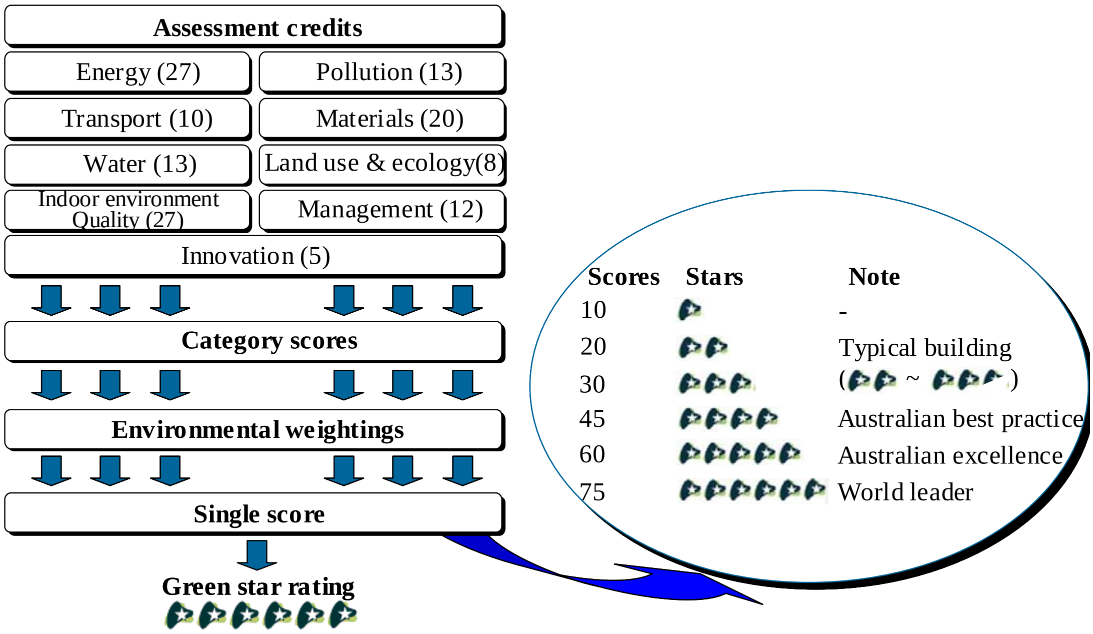

Figure 3 Schematic procedure of GreenStar

LCADesign

LCADesign is a fully integrated approach to automatic eco-efficiency assessment of commercial buildings (Tucker *et al*., 2003). It works off drawings of any building component in the complete 3D CAD building model and allows the viewing of environmental impacts resulting from building construction (Figure 4). It is a software tool developed to enable industry to make decisions on building environmental impacts based on a uniform level of information and access to environmental and economic costing for different products and designs. It was developed to meet the rapidly growing need of designers and regulators for real-time appraisal of design performance of built assets.

LCADesign exploits modern 3D, object-oriented CAD files that contain a wealth of building information. The software accesses the required 3D CAD detail through Industry Foundation Classes (IFCs), the international standard file format for defining architectural and constructional CAD graphic data as 3D real-world objects. Exploitation of this IFC format allows construction professionals to interrogate such graphic data as intelligent drawing objects and facilitates their analysis, for example, in terms of the performance of a design.

The automated take-off provides quantities of all components whose material make-up has been specified, calculates a complete list of all quantities of concrete, steel, glass, wood, plastic etc in the building, factors these with life cycle inventory results and provides impact assessments based on recognised environmental indicators such as the latest all-purpose indicator, Eco-Indicator 99.

The indicators provided by LCADesign comprise various environmental impacts based on the CML (resource depletion, global warming potential, ozone depletion, human toxicity, ecotoxicity, photochemical ozone creation, acidification and eutrophication) and Eco-Indicator 99 methods (carcinogens, respiratory organic and inorganic impact, climate change, radiation, ozone layer, ecotoxicity, acidification, eutrophication, land use, minerals, and fossil fuels) as well as embodied energy, embodied water and embodied carbon.

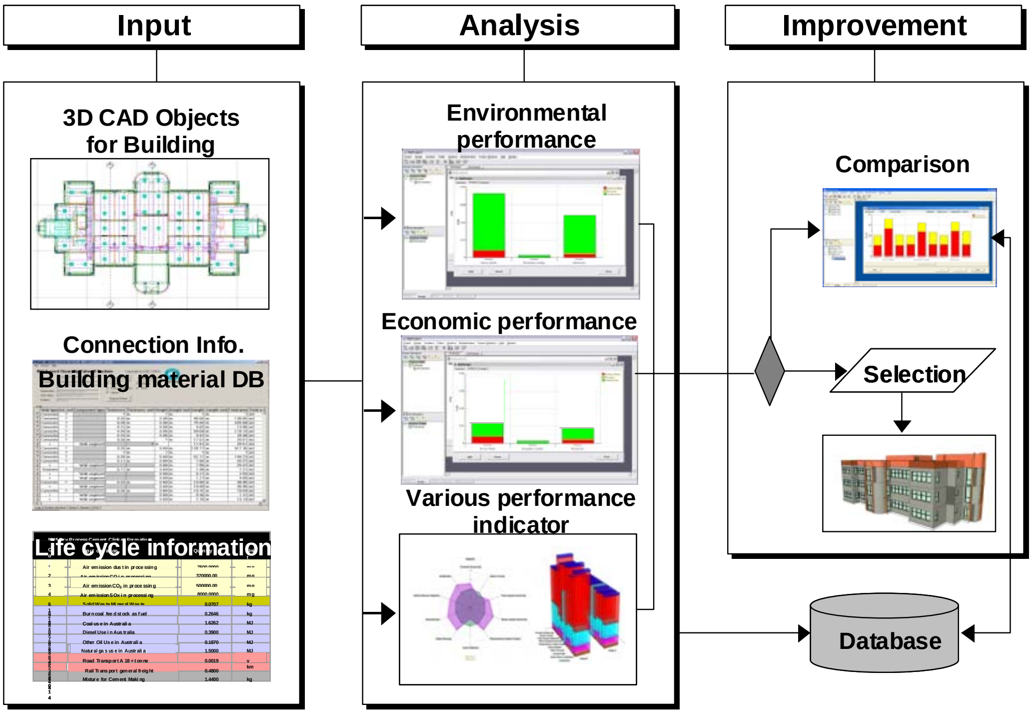

Figure 4 The LCADesign process

LCAid

LCAid was software developed by NSW Department of Public Works and Services (DWPS) for taking Life Cycle Assessment (LCA) information, which until now has been limited to LCA specialists, and makes it more accessible to other practitioners (e.g. architects, engineers, and portfolio managers) to make more complete environmental assessments.

LCAid aimed at the building designer, and was a decision making tool using LCA methodology to evaluate the environmental performance of design options and to identify the largest impacts over the entire life cycle of a building (Eldridge, 2002).

LCAid's usefulness in the design process stemmed from its seamless integration with other environmental software such as Ecotect, the Boustead Model and the extensive DPWS LCA database. Also LCAid has the feature of using material data exported from a 3D CAD model created in software such as Microstation or Autocad (or similar) like the LCADesign Tool developed by CSIRO.

A schematic diagram for LCAid is shown in Figure 5. Given known quantities of components (materials) that make up a building, LCAid calculated the environmental impacts of the building over its whole life. Building materials quantities could be entered in LCAid by manually entering quantities and assigning materials from the LCAid library or importing quantities generated by a 3-D architectural drawing and assigning materials to each building element (a 3-D model is not essential). Life Cycle Inventories (LCI) of building materials are stored in a library in LCAid and were based on the DPWS LCI database. Environmental impacts were calculated using the early Eco-Indicator 95 (now superseded) with the additional reporting of water consumption and solid waste produced.

Environmental attributes covered by LCAid comprised greenhouse effect, ozone depletion, heavy metals, nutriphication, acidification, carcinogenesis, summer smog, winter smog, energy and water consumption and solid wastes.

LCAid development has ceased and is not available commercially.

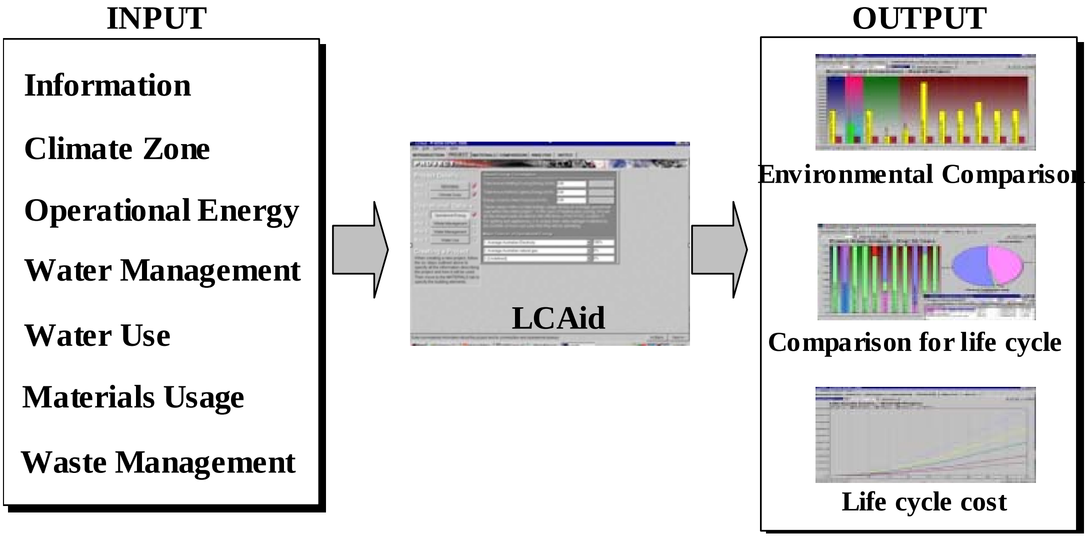

Figure 5 Schematic diagram for LCAid

LISA

LISA (LCA in Sustainable Architecture), developed by BHP and now supported by Blue Scope Steel, is a streamlined LCA decision support tool for construction (LISA, 2005). It was developed in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design.

LISA is designed to:

- Help identify key environmental issues in construction,
- Give designers an easy to use tool for evaluating the environmental aspects of building design,
- Enable designers and specifiers to make informed choices based on whole of life environmental considerations; i.e. life cycle analysis.

LISA can assess multi-storey offices, high-rise, wide span warehouse, road and rail bridges. Assessment criteria covered by LISA include greenhouse gas, VOC (non CH4), NOx, energy, SOx, SPM, and water.

At present only nominated developers are able to generate new case studies, or modify the underlying data or equations in existing case studies.

NABERS

The National Australian Built Environment Rating System (NABERS) (Department of Environment and Heritage, 2005) was designed to rate the environmental impact of the operation of buildings (commercial and residential) as a voluntary system used alongside other rating tools with the capacity to split the rating between tenant and landlord where required.

The system includes a broad range of topic areas where operational activities have an impact on the environment: energy use and greenhouse gas emissions, refrigerant use, water use, storm water run off and its pollution effects, sewage outfall effects, transport in relation to location of the building, landscape diversity, toxic materials emissions, handling of waste, indoor air quality and occupant satisfaction, as shown in Figure 6.

Enter data based on the heading

Category	Commercial Base	Commercial Tenancy	Residential
Energy	✓	✓	✓
Refrigerant impact	✓	-	-
Water	✓	-	✓
Sewage	✓	-	✓
Stormwater	✓	-	✓
Transport	✓	✓	✓
Landscape diversity	✓	-	✓
Waste	✓	✓	✓
Toxic materials	✓	✓	✓
Indoor air quality	✓	✓	✓
Occupant satisfaction	-	✓	✓

Summary/Overall Score

Figure 6 Schematic procedure of NABERS

This rating system is structured to have a series of categories, with "scores (maximum 5)" chosen as the unit of measurement. Summary scores are calculated as “overall greenhouse score”, “overall water score”, “site management score” and “occupant impact score”.

The overall greenhouse score is calculated by combining greenhouse emissions, calculated from “energy” and “transport” scores. These are rated on a scale from zero (0) to five (5).

The overall water score is the average of the water use, stormwater runoff and sewage outfall volume scores.

The site management score is the average of the stormwater pollution, landscape diversity, toxic materials and waste scores.

The occupant impact score is the average of the indoor air quality and occupant satisfaction scores.

The overall score is expressed as a score out of 10. Depending on the total scores earned, a building receives a rating level: world precedent (10), world class (9), best practice (8), good practice (7), upper average (6), average (5), lower average (4), poor (3), very poor (2), extremely poor (1) and failed (0).

NatHERS

NatHERS is a computer-based house energy rating system (SEAV, 2005) that can be used to give houses an energy efficiency rating from 0 to 5 stars.

The characteristics of the house envelope are assessed, including the levels of wall and ceiling insulation, the orientation of the house, window size and shading, and the thermal mass of the structure.

A 0-Star rating indicates that the house is inefficient and will be uncomfortable without a lot of heating in winter and a lot of cooling in summer. A 5-Star rating indicates that the house has achieved a high level of energy efficiency, and will require minimum levels of heating and cooling to be comfortable in winter and summer.

Houses which achieve a 5 star rating will be more comfortable to live in, have lower energy bills, and costs to install heating and cooling equipment should also be lower. Details of the house design and construction, and its orientation are entered into a computer program, along with a postcode, which links the program to a database of climatic information for the location.

A thermal simulation for the house is run using half hourly weather data, and the program calculates the energy required for heating and cooling the house (in MJ/m^2 per year) to achieve target levels of thermal comfort. The heating and cooling energy requirements are then used to calculate a Star Rating for the house.

Non-Australian tools for buildings and building products

ATHENA EIE

Athena EIE (Environmental Impact Estimator) is a LCA-based environmental decision support tool for building materials and buildings which was developed by Athena Sustainability Institute in 2000 (Athena Institute, 2005). Athena EIE helps designers achieve the best environmental footprint by showing side-by-side tabular and graphical comparisons of as many as five separate conceptual designs. It is a practical, easy-to-use decision support tool that provides high quality environmental data and assists with the complex evaluations required to make informed environmental choices. With Athena EIE all the basic LCA work is done out of the sight and mind of the user.

Assessment criteria cover embodied primary energy use, global warming potential, solid waste emissions, pollutants to air/water and natural resource use.

After specifying a design by selecting from typical assemblies or by entering specific quantities of individual products, Athena EIE breaks down the selected assemblies into their respective products for the purpose of applying the LCI databases. Then the results show the absolute inventory results or the six aggregated summary impact measures (e.g., energy consumption, air pollution index, water pollution index, global warming potential, resource usage, solid waste emissions) as a graphical or tabular format.

BEAT

BEAT is an LCA-based life cycle inventory tool for building products/building elements/buildings (DBRI, 2005). It is based on the Danish life cycle assessment method EDIP (Environmental Design of Industrial Products).

BEAT is a relational database designed using Microsoft Access. The database contains data for most conventional primary building products used in the Danish building industry (cement, concrete, gypsum boards etc.) and commonly used building elements. It also contains a number of energy sources and means of transport.

Assessment criteria covered by BEAT are shown Figure 7.

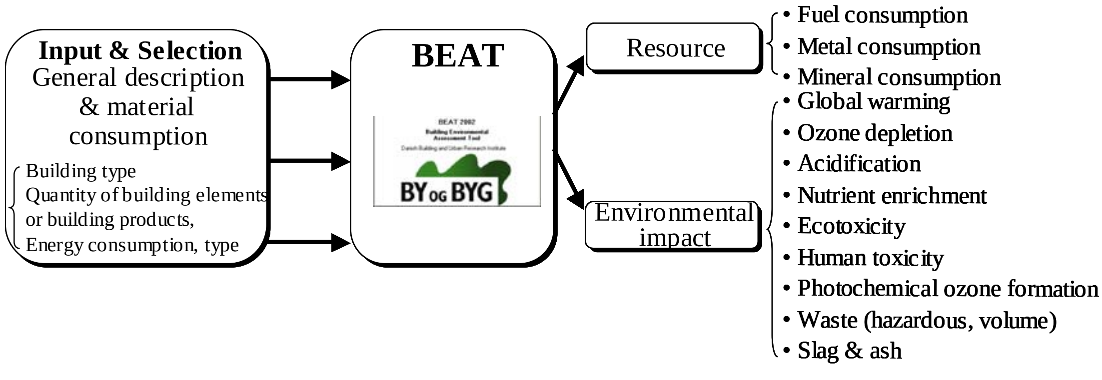

Figure 7 Schematic diagram and assessment criteria of BEAT

BEES

Building for environmental and economic sustainability (BEES) is an interactive computer design aid that helps users select building products for use in commercial office and housing projects in a way that balances environmental and economic criteria. A range of material options can be compared for different elements of the building, using graphical outputs of a range of environmental and economic criteria, considered individually or in combination (Lippiatt, 1999; 2000). At present the tool contains 65 building products. Future versions of BEES are planned that will cover building components, or collections of elements (Lippiatt and Rushing, 2002).

BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach. Economic performance is measured using the ASTM (American Society for Testing and Materials) standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performances are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements. Schematic diagram of BEES and the assessment criteria covered are shown Figure 8.

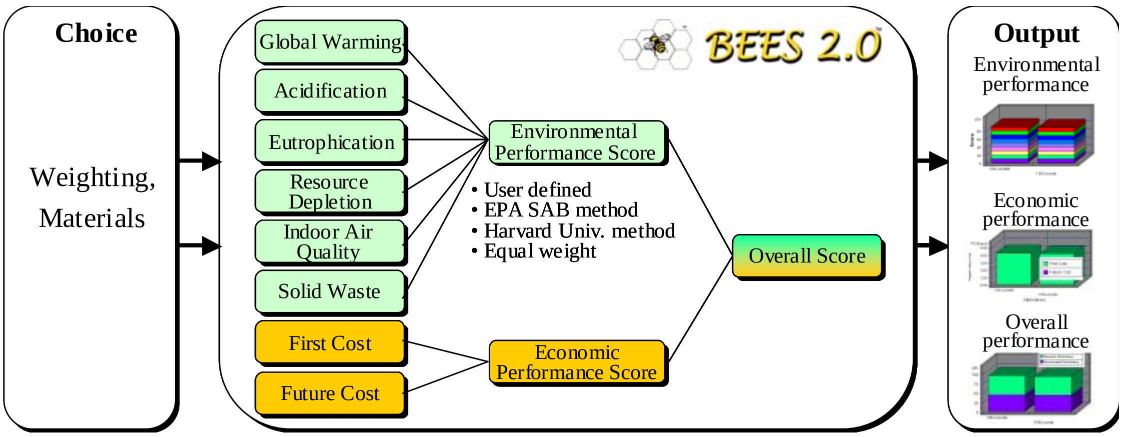

Figure 8 Schematic diagram of BEES

BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method), developed by BRE, UK (BRE, 2002), is a tool that allows the owners, users and designers of buildings to review and improve environmental performance throughout the life of a building. Environmental performance is assessed under nine main categories: management, health and comfort, energy, transport, water consumption, materials, land use, site ecology, and pollution (Figure 9).

For each of the criteria set out, the building is assessed against performance criteria set by BRE and awarded credits based on the level of performance against each criterion. The BREEAM assessments are carried out by certified assessors, but the pre-assessment checklists can be used by designers to identify and address requirements in the design process.

The percentage of credits achieved under each category is then calculated and environmental weightings are applied to produce an overall score for the building. The overall score then translated into a BREEAM rating of “PASS”, “GOOD”, “VERY GOOD”, or “EXCELLENT”.

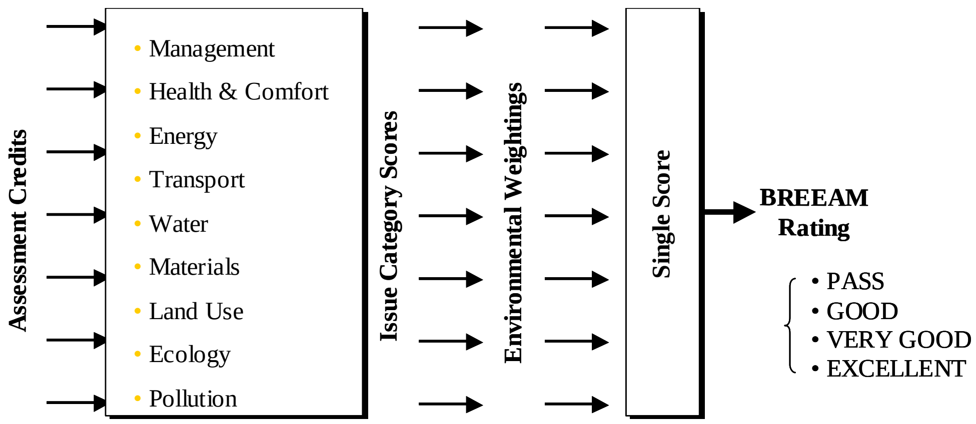

Figure 9 Schematic diagram of BREEAM

CASBEE

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) has been launched to establish a new system for environmental sustainable building in Japan (JSBC, 2003). CASBEE comprises a variety of assessment tools: Pre-design assessment tool, Design for Environment (DfE) tool, Eco-labeling tool, and sustainable operation and renovation tool. The CASBEE project, designated to be carried out over three years, is currently underway, and involves collaboration of the academic, industrial and governmental sectors.

CASBEE covers four assessment aspects: Energy, Resource, Local environments and Indoor environment.

Criteria are based on the structure of assessment items, Q: building environmental quality and performance is broken down into three categories; Q-1 indoor environment, Q-2 quality of service, and Q-3 outdoor environment on site. LR- reduction of building environmental loadings is also sub-grouped into LR-1 energy, LR-2 resources and materials, and LR-3 off-site environment. LR represents not the L: building environmental loadings itself, but the level of performance in minimizing building environmental loadings imposed outside the hypothetical boundary.

Ecoprofile

Ecoprofile, which is a method for simple environmental assessment of buildings, is a top down method for environmental assessment of existing office buildings. It includes three principal components that are given the designations external environment, resources and indoor climate (Pettersen, 2000). Each of the principal components has 4-6 sub-areas with a total of approximately 90 parameters assessed within these areas. Each sub-area is weighted. The method is based on the use of standardized schemes, questionnaires and reports to minimize the work of assessment and this makes it easy and cheap to use. The method has been under development since 1995, and has been operative since 1998. Criteria covered by Ecoprofile are shown in Figure 10.

Each criterion is scored and sub-criterion is weighted from 1 to 3 (except for energy as 10). Then, the results which are added scores for criteria are presented as bar charts for the major categories or target plot for detail within the major categories (resource depletion, environmental emission, energy consumption, and waste).

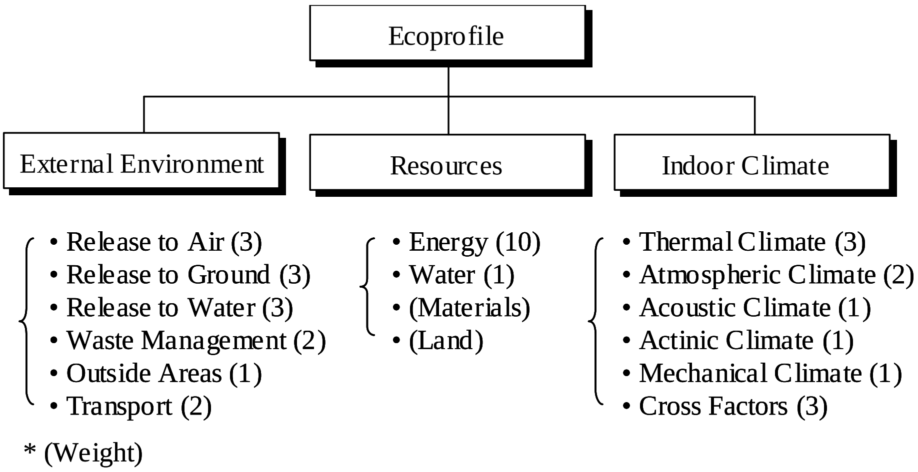

Figure 10 Assessment criteria and sub-criteria (weight) for ECOPROFILE

Eco-quantum

Eco-Quantum is a simulation-based tool intended to enable a designer to quickly identify environmental consequences of material choices and water and energy consumption of their designs (Mak and Knapen, 1997; Kortman *et al*., 1998). This tool calculates the environmental effects during the entire life cycle of the building from the time the raw materials are extracted, via production, building and use, to the final demolition or reuse. This includes the impact of energy, the maintenance during the use phase and the differences in the durability of parts of the construction related to the life span of the building.

Two versions of Eco-Quantum are available (Eco-Quantum Research and Eco-Quantum Domestic). Both are provided with information from a stand-alone version of the Dutch LCA program SimaPro 4 (Pre Consultants, 1997). Eco-Quantum Research is a tool for analyzing and developing innovative and complex designs for sustainable buildings and offices and Eco-Quantum Domestic is a tool which architects can apply to quickly reveal environmental consequences of material and energy use of their designs of domestic buildings.

Assessment criteria in ECOQUANTUM are energy consumption, water, material, air emission, water emission, and waste.

ENVEST

ENVEST (Environmental impact estimating design software) is the first UK software tool that estimates the life cycle environmental impacts of a building from the early design stage (BRE, 2005). ENVEST presently considers the environmental impacts of materials used during construction and maintenance, and energy and resources consumed over the building's life.

A schematic diagram for ENVEST is shown in Figure 11. Using minimal data entered, ENVEST allows designers to quickly identify those aspects of the building which have the greatest influence on the overall environmental impact. All impacts are assessed using Ecopoints – a measure of total environmental performance – which allow the designer to compare different designs and specifications directly (BRE, 2002).

Assessment criteria cover resource (fossil fuel depletion/extraction, minerals extraction, water extraction) and environmental loadings (climate change, acid deposition, ozone depletion, human toxicity, low level ozone depletion, ecotoxicity, eutrophication, waste disposal).

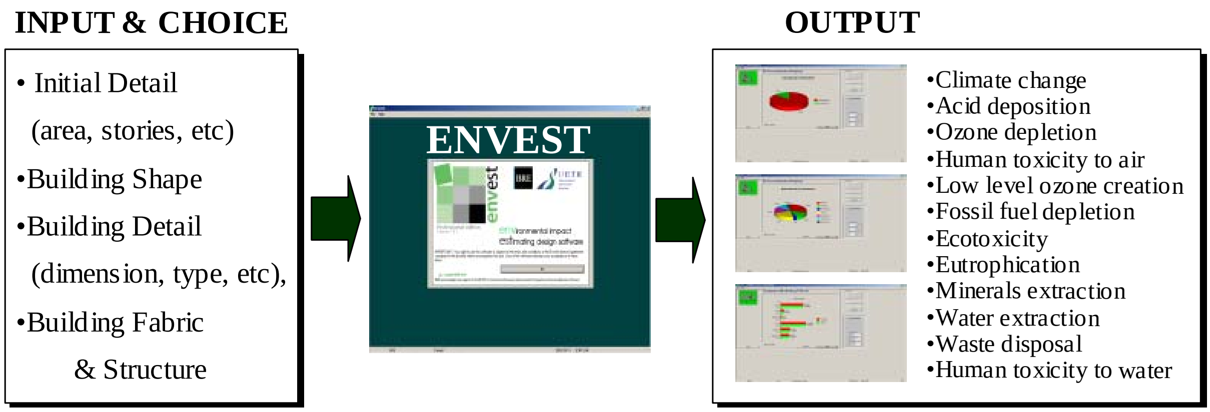

Figure 11 Schematic procedure for ENVEST

EQUER

EQUER is based upon a building model structured in objects (Center for Energy and Processes, 2005), this structure being compatible with the thermal simulation tool COMFIE. The functional unit considered is the whole building over a certain duration. Impacts due to the activities of occupants (e.g. home-work transportation, domestic waste production, water consumption) may be taken into account according to the purpose of the study: this possibility is useful e.g. when comparing various building sites with different home-work distances, waste collection system, water network efficiency etc.

Coupling life cycle analysis and energy calculations simplifies the use of the tool, which makes the comparison of design alternatives easier. The object structure is presented in Figure 12, according to a formalism defined in the STEP standard (concerning the exchange of computer data).

Assessment criteria provided in EQUER is an ecoprofile including the indicators listed in the following, either for the different phases or for different alternatives or projects: exhaust of abiotic resources, primary energy consumption, water consumption, acidification, eutrophication, global warming, non radioactive waste, radioactive waste, odours, aquatic ecotoxicity, human toxicity, and photochemical ozone (smog).

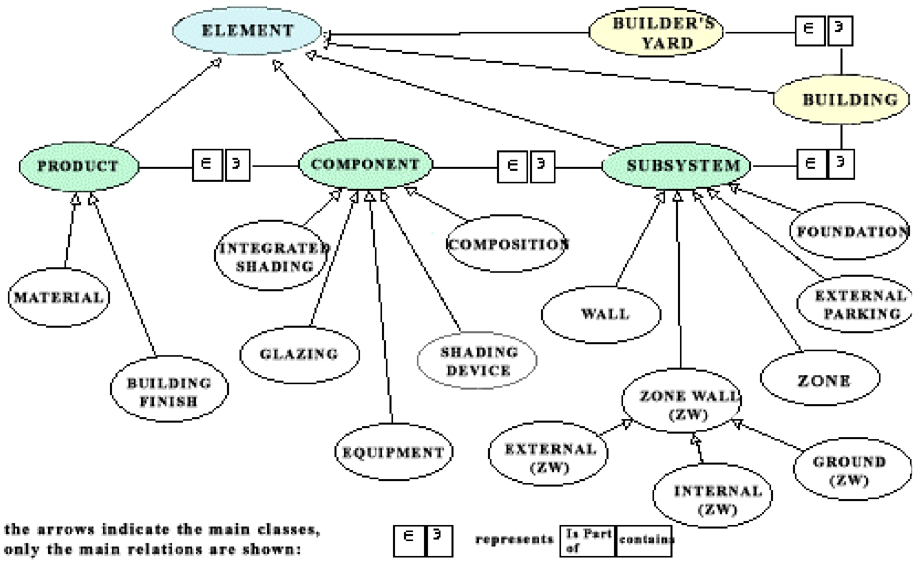

Figure 12 Technical building objects structure of EQUER

GBTool

The Green Building Challenge (GBC) is a consortium of over twenty countries that is developing and testing a new method of assessing the environmental performance of buildings (Larsson and Cole, 2001). The assessment framework has been produced in the form of software, named GBTool that facilitates a full description of the building and its performance and also allows users to carry out the assessments relative to regional benchmarks.

GBTool offers spreadsheets for self assessment, taking into account regional or local variations. Assessment criteria for GBTool comprise resource consumption, environmental loadings, indoor environmental quality, service quality, economics, pre-operation management and commuting transport as shown in Figure 13. The first four criteria (resource consumption to service quality) are considered core requirements in the GBC assessment. These criteria have sub-criteria to be scored for the tested building using the –2 to +5 assessment scale. The remaining criteria (economics, pre-operation management and commuting transport) are important but are not scored.

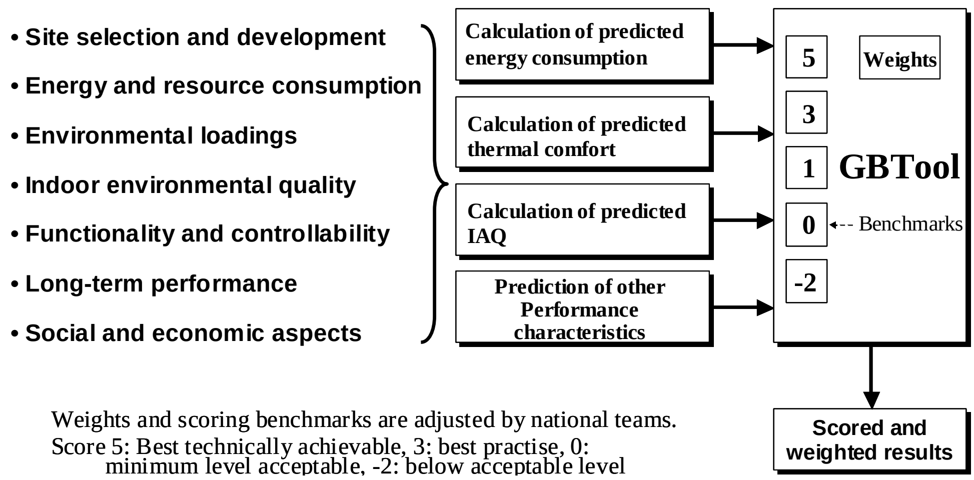

Figure 13 The GBTool framework

Green Globe

Green Globe is an online building and management audit tool (ECD Energy and Environment, 2005) that helps property owners and managers for commercial and multi residential buildings measure the environmental performance of their buildings against best practices in areas such energy, water, hazardous materials, waste management and indoor environment. It is web-enabled self-assessment based on BREEAM/Green Leaf. Green Globe uses a confidential questionnaire, and generates an online report. Assessment criteria and sub-criteria covered by Green Globe are shown in Figure 14.

Green Globe is not only the first interactive, web-based, commercial green building assessment protocol, it is the only web-based assessment that actually guides the integration of green principles into a building's design.

Green Globe identifies a building's environmental strengths and weaknesses, instantly recommends sustainable design improvements, and automatically generates links to engineering, design and product sources. Originally designed for use in Canada, Green Globe is endorsed and recommended by the Canadian Government.

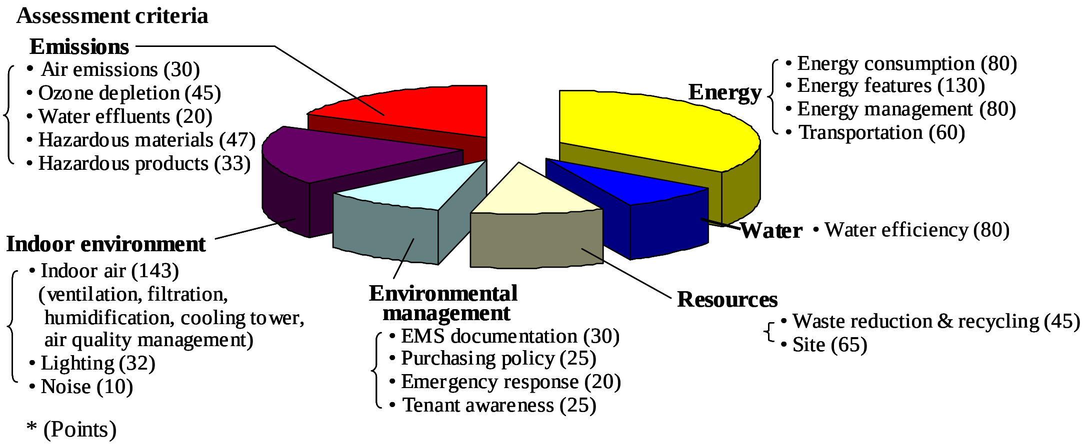

Figure 14 Assessment criteria and corresponding points in Green Globes

GreenCalc

GreenCalc is a computer tool to calculate the environmental load of a Dutch office building. It is divided into four modules: materials, energy, water usage and mobility (GreenCalc, 2005).

- Material module: choice of materials, quantities, insulating values
- Energy module: energy consumption in the operation phase (use of building, air-conditioning, ventilation, lighting.)
- Water usage: water consumption in the operation phase (facilities, sanitary facilities, rainwater etc.)
- Mobility: accessibility from home to work place (location, public transport, own transport)

Results are expressed in terms of money as so-called submerged environmental costs (cost per m^2, total score on a scale from 1 - 2000. The average building built in 1990 has a score of 100 and the goal for 2050 is buildings with a score of 2000)

Assessment criteria comprise environmental cost for material use (foundation, envelope, finishing, completion, wiring/piping, furnishing, and site), environmental cost for energy (use of building, air-conditioning, hot tap water, lighting, installation/systems), environmental cost for water, and environmental cost for mobility.

LEED

The LEED™ (Leadership in Energy and Environmental Design) is a priority program of the US Green Building Council, and is a voluntary, consensus-based, market driven building rating system (US GBC, 2002).

LEED™ is a self-assessing system designed for rating new and existing commercial, institutional and high-rise residential buildings. It is a feature-oriented system where credits are earned for satisfying each criterion. The LEED™ rating system uses a simplified checklist format that facilitates its use in the design process – design teams often use the checklist as the basis for discussions of which strategies and credits they will try to achieve in the building.

LEED™ awards ratings of certified, silver, gold, and platinum. To obtain a rating, a building must meet seven prerequisites and then obtain points for credits related to sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. Assessment criteria covered by LEED™ comprise sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality and innovation and design process. Each of the criteria has more detailed sub-criteria.

Each criterion is specified as credits and the user selects criteria for scoring. All criteria are weighted equally, except for number of points assigned which effectively provides a weighting. Different levels of green building certification are awarded based on the total credits earned (Figure 15).

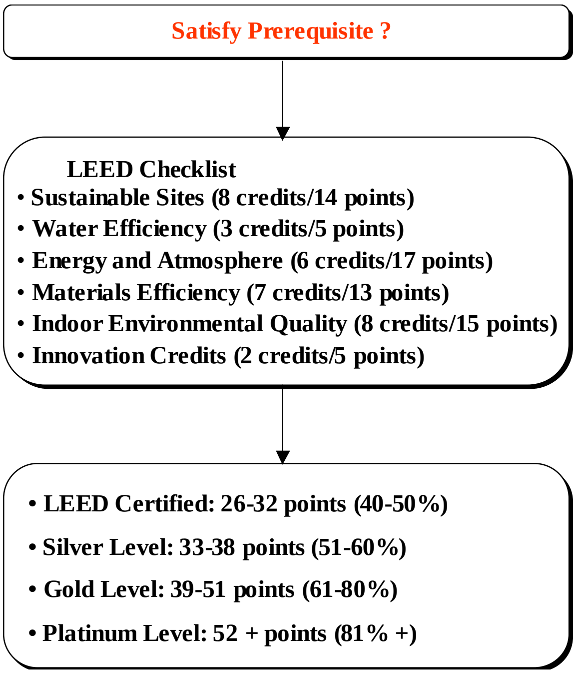

Figure 15 The LEED rating system

Comparison of tools

Generally buildings are designed to meet building code requirements, whereas green building design challenges designers to go beyond the codes to improve overall building performance, and minimize the environmental impacts and cost. Most of these building evaluation tools have been developed to transform the design goal into specific performance objectives and provide a framework to assess the overall design. These are used by design professionals for making design decisions, material and equipment selections and in determining the performance of particular aspects of a building design.

Sustainable design for building requires selection of environmentally friendly construction methods and materials. Recycling, minimizing resources and environmental impacts required to produce these materials are all critical for making design decisions. During the early design stages, it is important to consider all possible design options and evaluate their life cycle impact. The information available during this preliminary design stage is limited and requires tools that can guide designers with default data and intelligence.

Table 1 to Table 6 provide a summary of the characteristics of the tools and systems described above in a form based on an earlier review of environmental assessment tools (Foliente *et al.*, 2004) which considered level, coverage and weighting, data needs, design/building, end-use and impact assessment/scale as well as impact criteria.

The evaluation tools listed in Table 1 to Table 6 generally cover the building level, based on some form of life cycle assessment database except for Ecospecifier and Evergen in the Australian tools list and BEES and ECOQUANTUM for non-Australian tools. These exceptions focus on the characteristics of building products rather than the performance of the whole building or element assembly.

Table 1 Summary of Australian evaluation tools for buildings and building materials

Tool	Tool type	Purpose	Single value	Provider
ABGR	Voluntary	Design & improvement	√	NSW Department of Commerce
AccuRate	Regulatory (Australia wide)	Thermal performance	√	CSIRO
BASIX	Regulatory(NSW)	Design & improvement	√	NSW DIPNR**
BERS	Regulatory (QLD)	Thermal performance	√	CSIRO
Ecospecifier	Voluntary	Building material chosen in design	-	RMIT & EcoRecycle Victoria
EPGB	Voluntary	Design & improvement	-	NSW Department of Commerce
EVERGEN	Voluntary	Building material chosen in design	-	CSIRO
Firstrate	Regulatory (VIC, SA)	Thermal performance	√	SEAV Victoria++
Green star	Voluntary	Design & improvement	√	Green Building Council
LCADesign	Voluntary	Design &performance	√	CRC CI
LCAid	Voluntary	Design &performance	-	NSW Department of Commerce
LISA	Voluntary	Design &performance	-	Centre for sustainable Technology
NABERS	Voluntary	Design & improvement	√	DEH*
NatHERS	Regulatory (SA, ACT, VIC)	Thermal performance	√	CSIRO

DEH: Australian Government Department of the Environment and Heritage (DEH)
DIPNR: Department of Infrastructure, Planning and Natural Resources (DIPNR)
SEAV: Sustainable Energy Authority Victoria (SEAV)
CRC CI: Cooperative Research Centre for Construction Innovation (CRC CI)

Table 2 Application type by Australian evaluation tools for buildings and building products

Tool	End-use	Application	
ABGR	Building	New and existing	Commercial building
AccuRate	Building	New	Residential building
BASIX	Building	New	Residential building
BERS	Building	New	Residential building
Ecospecifier	Material	-	Building material
EPGB	Building	New	Commercial & residential buildings
EVERGEN	Material	-	Building material
Firstrate	Building	New	Residential building
Green star	Building	New and existing	Commercial building
LCADesign	Building/Material	New	Commercial building
LCAid	Building/Material	New	Commercial & residential building
LISA	Building/Material	New	Commercial & residential building
NABERS	Building	Existing	Commercial & residential buildings
NatHERS	Building	New and existing*	Residential building

*Existing building for sale in ACT

Table 3 Assessment level, development coverage, and environmental attributes by Australian building evaluation tools

Tool	Assessment level	Phase*	Environmental Attributes
ABGR	Whole building	O & M	Energy
AccuRate	Assembly & whole building	D, O & M	IEQ (termal comfort), energy
BASIX	Assembly & whole building	P and D	IEQ, energy, water, environmental loadings
BERS	Assembly & whole building	D, O & M	IEQ (termal comfort), energy
Ecospecifier	Product	D, O & M	IEQ, material/resource, energy, water, environmental loadings, biodiversity
EPGB	Whole building	P, D and O&M	IEQ, Material/resource, transport, energy, water, environmental loadings, biodiversity
EVERGEN	Product	P, D and O & M	IEQ, material/resource, energy, water, environmental loadings, biodiversity
Firstrate	Assembly & whole building	D, O & M	IEQ (thermal comfort), energy
Green star	Whole building	D, O & M	IEQ, Material/resource, transport, energy, water, environmental loadings, biodiversity
LCADesign	Assembly & whole building	P, D and O & M	IEQ (air quality), material/resource, energy, water, environmental loadings
LCAid	Assembly & whole building	P, D, O & M and EoL	Material/resource, energy, water, environmental loadings
LISA	Assembly & whole building	D, O & M and EoL	Material/resource, energy, water, environmental loading (global warming), air emission
NABERS	Assembly & whole building	O & M	IEQ, material/resource, transport, energy, water, environmental loadings, biodiversity
NatHERS	Assembly & whole building	D, O & M	IEQ (thermal comfort), energy

* P: Planning, D: Design, O & M: Operation and Maintenance, EoL: End-of-Life

Table 4 Summary of non-Australian building evaluation tools

Tool	Type	Purpose	Single value	Provider
ATHENA EIE	Voluntary	Design & improvement	√	Athena Institute, Canada
BEAT	Voluntary	Design & improvement	-	DBUR, Denmark
BEES	Voluntary	Building material chosen in design	√	NIST, USA
BREEAM	Voluntary	Design & improvement	√	BRE, UK
CASBEE	Voluntary	Design & improvement	√	JSBC, Japan
ECOPROFILE	Voluntary	Design & improvement	-	NBI, Norway
ECOQUANTUM	Voluntary	Building material chosen in design	√	IVAM, Netherlands
ENVEST	Voluntary	Design & improvement	√	BRE, UK
EQUER	Voluntary	Design & improvement	√	France
GBTool	Voluntary	Design & improvement	√	NRC, Canada
Green Globes	Voluntary	Design & improvement	-	ECD Energy & Environment, Canada
GreenCalc	Voluntary	Design & improvement	√	NIBE, Netherlands
LEED	Voluntary	Design & improvement	√	US GBC, USA

NRC: National Research Council (NRC) Canada
BRE: Building Research Establishment ltd
US GBC: US Green Building Council
JSBC: Japan Sustainable Building Consortium
NBI: NORWEGIAN BUILDING RESEARCH INSTITUTE (NBI)
DBUR: Danish Building and Urban Research Institute (DBUR)
NIST: National Institute of Standards and Technology (NIST)

Table 5 Application type by non-Australian building evaluation tools

Tool	End-use	Application	
ATHENA EIE	Building/material	New	Commercial & residential buildings
BEAT	Building	New	Commercial & residential buildings
BEES	Product	-	Building material
BREEAM	Building	New and existing	Commercial & residential buildings
CASBEE	Building	New	Commercial & residential buildings
ECOPROFILE	Building	New	Commercial building
ECOQUANTUM	Product/Parts	-	Building material
ENVEST	Building	New	Commercial building
EQUER	Building	-	Residential building
GBTool	Building	New	Commercial & residential buildings
Green Globes	Building	New and existing	Commercial & residential buildings
GreenCalc	Building	New and existing	Commercial building
LEED	Building	New and existing	Commercial & residential buildings

Table 6 Assessment level, development coverage, and environmental attributes by non-Australian building evaluation tools

Tool	Assessment level	Phase*	Environmental attributes
ATHENA EIE	Material, assembly & whole building	D, O & M	Material/resource, transport, energy, environmental loadings
BEAT	Material & assembly	D, O & M, EoL	Waste, energy, water, environmental loadings
BEES	Material & assembly	D, EoL	IEQ, energy, water, environmental loadings
BREEAM	Assembly & whole building	P, D, O & M and EoL	IEQ, material/resource, transport, energy, water, environmental loadings, biodiversity
CASBEE	Whole building	P, D, O & M and EoL	IEQ, material/resource, transport, energy, water, environmental emissions
ECOPROFILE	Whole building	D, O & M, EoL	IEQ, material/resource, transport, energy, water, environmental emissions, biodiversity
ECOQUANTUM	Material & assembly	D, EoL	Material/resource, energy, environmental emissions
ENVEST	Whole building	D	Material/resource, energy, water, environmental loadings
EQUER	Assembly & whole building	D, O & M, EoL	Waste, energy, water, environmental loadings
GBTool	Whole building	P, D, O & M and EoL	IEQ, material/resource, transport, energy, water, environmental loadings
Green Globes	Whole building	D, O & M	IEQ, material/resource, transport, energy, water, environmental loadings
GreenCalc	Assembly & whole building	D, O & M, EoL	Material/resource, transport, energy, water
LEED	Whole building	D, O & M, EoL	IEQ, material/resource, transport, energy, water, environmental loadings, biodiversity

* P: Planning, D: Design, O & M: Operation and Maintenance, EoL: End-of-Life

Different tools are available for different requirements of the user, depending on the nature of technology or design strategy being evaluated. The methodologies of these building assessment tools vary widely and include:

- life cycle impact assessment (resource usage and emissions to the environment),
- judgmental evaluation for selection of materials and technologies,
- analysis and simulation tools for calculating energy consumption,
- lighting effects, and
- measurement of indoor environmental quality.

Some of these tools can be used in the detailed design stages to evaluate whole building performance such as energy consumption and environmental quality. These tools further can be classified into two major categories, Building Life Cycle Assessment (LCA) tools and simulation tools for energy and lighting performance evaluation.

The tools also can be categorised as either **assessment** tools (LCAid, LCADesign, LISA, ENVEST, ATHENA EIE, Ecoquantum, Ecoprofile, BEAT, GreenCalc, BEES and EQUER) listed in Table 1 to Table 6 which provide quantitative performance indicators to help make decisions on design alternatives or **ratings** tools (NABERS, GreenStar, EPGB, BASIX, ABGR, Ecospecifier, Evergen, NatHERS, AccuRate, BERS, Firstrate, GBTool, BREEAM, Green Globes, LEED and CASBEE) which determine the performance requirements and level of green building rating based on the rating methodology used.

The whole building tools in general focus on the following seven categories of building design and life cycle performance.

- Material/resource,
- Energy,
- Water,
- Indoor Environment Quality (IEQ),
- Transport,
- Environmental loadings, and
- Biodiversity

For each category in the existing tools, there are a varying number of prerequisites and credits with specific design and performance criteria (see Appendix A - Environmental indicators for Australian building assessment tools for details of these indicators for each toll reviewed).

Most of tools listed in Table 1 to Table 6 are voluntary in nature except for BASIX (which is compulsory in NSW for residential building) and FirstRate (or NatHERS) (which is used for regulation for thermal efficiency).

Only a few tools concentrate solely on assessing or rating performance in the operating years post-construction (NABERS and ABGR) but several are used in the design stage with evaluations focussed on one aspect (energy) of the operational performance of the building or building product (Accurate, BERS, Ecospecifier, First Rate, NatHERS, and Green Globes).

All the tools listed above are intended to document an integrated assessment at the overall project level, usually for new buildings. To perform these assessments, baseline and actual building performance for energy consumption, embodied energy and other performance levels need to be determined using analysis and design tools.

ENVIRONMENTAL INDICATORS

Requirements for environmental indicators

A number of stakeholders are involved with a building over its life as shown in Table 7. As these stakeholders are showing concern about environmental impacts, building environmental performance has become a significant issue. These stakeholders, however, require different needs to meet their different performance objectives over the life cycle of a building. Thus, there is no homogeneous set of performance indicators for environmental performance of buildings, their components or materials used therein.

Table 7 Example of stakeholders in the life cycle of a building

Life cycle	Stakeholder
Resource extraction/manufacturing	Supplier, manufacturer, constructor etc.
Construction	Designer, constructor, future owner and operator, investor etc.
Operation/maintenance	Building manager, occupant (tenant, owner/occupier) etc.
Refurbishment/demolition	Owner etc.
Recycling/reuse/disposal	Owner, governor etc.

Each of the stakeholders can get some of their required information for each stage of a building's life cycle without regard to whether it is what they want or not. This overwhelming amount of information can be confusing and difficult to understand for the results obtained. Thus, building stakeholders require simple and easy to interpret environmental performance indicators for their buildings or components.

Environmental indicators for building performance can give good information which all of stakeholders want. Building environmental performance indicators can support their requirements for three major purposes to:

- Supply information on environmental problems, in order to enable them to assess their seriousness effectively,
- Monitor the environmental status of their building, and
- Support building development and priority setting, by identifying key factors that cause pressure on the environment.

To be a used properly by each stakeholder, environmental performance indicators should be related to measurable properties. A performance indicator is not simply a piece of information or a statistic. An indicator implies comparison and in practice generally contains two or more variables and can be of two types – performance measures and performance indices – where (Tucker and Taylor, 1990):

- A *performance measure* is usually a ratio or combination of items which result in value such as resource usage per square metre, emissions per annum etc, and
- A *performance indicator* is a ratio of two performance measures of the same type which reflects relative performance often by comparison with a standard or norm.

Environmental performance indicators should be based on international standards or common practice. The required characteristics of indicators include the abilities to (Sigurjonsson *et al.*, 2002):

- Provide a representative picture of an environmental condition of the building sector's status concerning environmental burden,
- Be simple, easy to interpret and able to show trends over time,

- Be responsive to quick changes in the environment related to human activities,
- Provide a basis for international comparisons,
- Be well founded in technical and scientific terms,
- Be based on international standards and an international consensus concerning its validity,
- Be adequately documented and of known quality, and
- Be updated at regular intervals in accordance with reliable procedures.

Environmental performance indicators

Environmental performance is one aspect of performance of buildings and building products that is becoming of more interest to stakeholders in the building industry. The significance of environmental performance in the decision making process involved in producing a building varies depending on the stakeholder involved. Building construction companies are motivated to improve environmental performance for a number of reasons, directly or indirectly, by:

- Saving energy (directly, indirectly linked to energy costs and environmental burdens),
- Reduction of resource consumption (directly, indirectly linked to material costs inputted and environmental burdens),
- Reduction of environmental burdens (indirectly, also linked to market risk),
- Incurring less costs (directly, also linked to market risk), and
- Reduction of market risk (indirectly).

ISO TC 59 (2002a) suggests that environmental performance of buildings should include a structured list of issues of the environmental performance of buildings. This list includes issues of environmental impact of the production of buildings' components, construction, operation, repair and maintenance, refurbishment, and demolition. As is common with any structured list of performance measures or indicators, performance issues begin with high level categories with sub-categories (and often sub-sub-categories) before finally resulting in a level of detail which can be measured.

In addition, environmental comfort and benefits of buildings may be included as issues of environmental performance of buildings.

Mandatory and optional lists of environmental performance indicators and their corresponding sample indicators for environmental performance issues are shown in Table 8.

Table 8 Minimum list of environmental performance issues for building assessment (ISO)

Categories of mandatory issues to be included in the methods	Sub-categories	Examples of issues assigned to the category	
Indoor environment	1 Thermal comfort	1.1 Performance of room temperature control 1.2 Degree of moisture control 1.3 Vertical distribution of air temperature 1.4 Air velocity	M
	2. Lighting	2.1 Degree of visual access to the exterior & daylight access 2.2 Performance of access to day lighting 2.3 Performance of anti-glare measures 2.4 Illumination levels 2.5 Degree of lighting controllability	M
	3. Air quality	3.1 Degree of sources control 3.2 Performance of ventilation 3.3 Performance and quality of operation plan	M
	4 Noise & acoustics	4.1 Level of noise 4.2 Level of sound insulation 4.3 Level of sound absorption	M
Energy	1. Operational energy	1.1 Total primary energy consumption in operation	M
	2. Efficient operation	2.1 Performance of monitoring 2.2 Performance of operational management system including commissioning	M
	3. Thermal load	3.1 Building orientation 3.2 Thermal load of windows 3.3 Insulation level of exterior wall and roof	M
	4.Natural energy utilization	4.1 Degree of direct utilization of natural energy 4.2 Degree of indirect utilization of natural energy	M
	5.Building systems' efficiency	5.1 Performance of HVAC system 5.2 Performance of ventilation system 5.3 Performance of lighting system 5.4 Performance of water heating system 5.5 Performance of elevator system	M
Resources and materials	1. Water consumption	1.1 Amount of water consumption 1.2 Degree of utilization of rainwater and grey water	M
	2. Resource productivity	2.1 Degree of use of recycled materials 2.2 Degree of use of renewable resources 2.3 Degree of reuse of existing skeleton. 2.4 Durability of the materials 2.5 Performance of waste disposal	M
	3. Avoidance of pollutant materials	3.1 Degree of avoidance of hazardous materials 3.2 Degree of avoidance of CFCs and halons	M
Environmental impacts to surroundings	1. Pollution	1.1 Performance of run-off management 1.2 Degree of acidification 1.3 creation of photo-oxidants 1.4 Degree of nutrification 1.5 Degree of emissions of water pollutants 1.6 Degree of emissions of soil pollutants	M
	2. Load on local Infrastructure	2.1 Load on traffic management systems 2.2 Load on waste treatment systems	M
	3 Wind damage related issues		O
	4 Light pollution related issues		O
	5 Heat island effect related issues		O
	6 Load on local Infrastructure related issues	6.1 Load on sewage treatment systems 6.2 Degree of access to sunlight of adjacent property	O

Quality of service	1. Service ability related issues	1.1 Functionality and workability 1.2 Mentality: Coziness 1.3 Mentality: Comfort 1.4 Privacy	O
	2. Durability related issues	2.1 Earthquake-resistance 2.2 Performance of daily maintenance/updating and frequency	O
	3. Flexibility & Adaptability related issues	3.1 Space margin 3.2 Floor load margin 3.3 Aadaptability to various requirements	O
Outdoor environment	1. Maintenance and creation of ecosystems related issues		O
	2. Townscape & landscape related issues		O
	3. Local characteristics & culture related issues		O

M: Mandatory list, O: Optional list

These environmental issues can be classified into 3 main categories: energy consumption, resource consumption, and other environmental impacts.

- *Total energy consumption*

The main purpose is to reduce both energy consumption and the share of non-renewable energy. Also, reducing total energy consumption has a flow on effect of reducing the number of environmental impacts caused by energy consumption (i.e., acidification from SOx and NOx, greenhouse effect from CO_2 emission etc.)

- *Resource consumption including water (total input of materials and water used)*

The purpose is to reduce and optimize the non-renewable material resources and waste generation as well as reduce water consumption.

- *Other environmental impacts to human health or ecosystem*

The main purpose is to provide a measure of impacts concerning the effects of water consumption, emissions to water, air and indoor environmental conditions, on human health or flows into ecosystems.

Table 9, Table 10 and Table 11 summaries the key environmental performance indicators in each of the above environmental issues by way of quantitative values which can be readily measured for the building or building product being assessed.

Table 9 Key performance indicators for energy

Issue	Key performance indicators	Unit
Energy	Initial embodied energy	MJ/m^2/yr
	Operating energy - Annual HVAC energy consumption - Annual site lighting energy consumption - Annual plug load (tenant equipment) energy consumption - Annual other building system energy consumption - Annual service hot water energy consumption	MJ/m^2/yr

Table 10 Key performance indicators for resources

Issue	Key performance indicators	Unit
Material	Amount of materials used for initial building production	Kg or cost/m^2/yr
	Material consumption for building construction (kg/m^2)	Kg/m^2
	Reuse and recycling of construction materials	%, Kg/m^2
Water	Total water consumption	m^3/ m^2
	Annual water consumption	m^3/ m^2/yr
	Potable water use for - Toilet flushing and urinals in public washrooms - Other sanitary uses - Other occupant functions - Building equipment operation Commercial kitchen facilities, where applicable Water consumption	m^3/yr
	Recycled/Reused water	m^3/yr
Land	Net area of land used for building	m^2
	Gross floor area	m^2

Table 11 Key performance indicators for other impacts

Impact	Indicators	Unit
Global warming	Greenhouse gas emission for materials	Kg CO_2 eq/kg
	Greenhouse gas emission for construction	Kg CO_2 eq/m^2
	Greenhouse gas emission from building operation	kgCO_2 eq/m^2/yr
Ozone depletion	Emissions of kg CFC11 equivalent from building material production	Kg CFC-11 eq/kg
	Annual emissions of kg CFC-11 equivalent ozone depleting gases - From operation - In HVAC system	Kg CFC-11 eq/m^2/yr
Photochemical oxidant creation	Emissions leading to photo-oxidants from building operations	Kg C_2H_2 eq/m^2/yr
Acidification	Atmospheric emissions of kg SO2 equivalent from building production	Kg SO_2 eq/m^2
	Kg of SO2 equivalent acidifying compounds emissions from construction	Kg SO_2 eq/m^2
	Annual emission of kg SO2 equivalent compounds from operation and maintenance for area and occupancy	Kg SO_2 eq/m^2/yr/occupant
Eutrophication	Nitrogen and phosphorus compounds emissions	Kg PO_4^{--}eq/m^2
Water pollutants	Storm water flows disposed of on site	m^3/m^2/yr
	Sanitary waste water flows disposed of on site	m^3/m^2/yr
Waste emission	Construction waste	Kg/m^2
	Hazardous wastes resulting from renovation or demolition wastes	Kg/m^2
	Annual solid waste from occupant during operation/ maintenance	Kg/m^2/occupant/yr
	Operational waste generation	Kg/m^2
	Recycled waste from operation/maintenance	Kg/m^2/occupant/yr
IAQ	VOC emissions in interior spaces	Mg/m^3/m^2
	Measured CO_2 concentrations in indoor	ppm/m^2
	Suspended particulate matter (PM10), 24h	Mg/m^3/m^2
Comfort/ Noise	Provision of daylighting in principal work areas	%/m^2
	Ambient illumination levels in principal work areas	Lx/m^2
	Visual access to the exterior from principal work areas	M/m^2
	Noise level	DB/m^2

Environmental performance indicators for existing tools

There are many possible indicators (e.g., see the website for CRISP (2003)), and they can be organised in various ways. A common challenge for the assessment and rating tools is how to present large quantities of information from many different disciplines and what indicators at which aggregation levels to present. The question, "*What kinds of environmental performance indicators should be included in a category,*" has been a hot issue of debates for tool developers or users (Udo de Haes *et al.*, 1999; Bare *et al*., 2000; Klopffer, 2002).

The list of environmental performance indicators usually includes not only issues of environmental impact of the production of a building's components, construction, operation, repair and maintenance, refurbishment, and demolition, but also the environmental comfort and benefits to building occupants (ISO, 2002b). The Sustainability Advisory Council of NSW suggests ten broad categories for the sustainability index of a building, such as social, transport, water, alteration water, stormwater, energy, alteration energy, waste, indoor air quality, and materials (Sustainability Advisory Council, 2002). In relation to these, fourteen kinds of principal targets are suggested for sustainable buildings in Europe (Mesureur, 2002; Deroubaix, 2002). These criteria are similar to the suggestion of Cole *et al.* (2000), in which economic and social concerns as well as environmental aspects of sustainability should be considered as criteria in building assessment.

Assessment tools have utilized different approaches for their environmental performance criteria as shown in Table 12 (Also see Appendix A - Environmental indicators for Australian building assessment tools and Appendix B - Environmental indicators for Non-Australian building assessment tools for more detailed indicators).

Table 12 Comparison of environmental building performance criteria for selective tools

Tool	Performance criteria	Unit
BREEAM	Management	-
	Energy (operational use, CO_2)	kg $CO_2/m^2/yr$
	Health and well-being (Indoor and external issues)	-
	Pollution (air, water)	-
	Transport (CO_2, location factors)	-
	Land use (greenfields, brownfields)	-
	Ecological value of site	-
	Materials	-
	Water consumption and efficiency	m^3/person/yr
LEED	Site	-
	Energy	%
	Water	-
	Materials (efficiency)	%
	Indoor environmental quality	-
NABERS	Energy/greenhouse	kg CO_2/m^2
	Refrigerant GWP	kg CO_2/m^2
	Refrigerant ODP	kg CFC eq/m^2
	Transport	KgCO_2/person
	Water use	m^3/m^2/year
	Stormwater	m^3/year
	Sewage outfall	m^3/year
	Landscape diversity	m^2
	Waste	Kg
	Toxic materials	-
	Indoor air quality	ppm
	Occupant satisfaction	-

Source: BREEAM (Grace, 2000), LEED (US GBC, 2002), NABERS (DEH, 2003)

As shown in Table 12, some tools use *quantitative* indicators such as annual energy consumption (MJ/m^2/year) and CO_2 emission (kg CO_2 eq/m^2/year) for energy or global warming impact for a building. On the other hand, some tools use *qualitative* indicators such as reduction efforts for energy or global warming gases for a building by awarding points for existence of a process or not as part of their scoring system. These qualitative scores are not necessarily performance indicators.

The understanding of what type of indicators users really want is difficult with questions such as 'How these indicators need to be presented', and 'Which type of indicator users can best cope with their decision making?' requiring practical outcomes Despite a number of debates (Udo de Haes *et al*., 1999; Bare *et al*., 2000; Klopffer, 2002), there is not general agreement on indicators. Selection of environmental performance indicators has been influenced by environmental policy documents, available models and data, the type of applications at hand, and the background of the developers involved (Hofstetter and Mettier, 2003). Therefore, only quantitative indicators are considered in this report.

INDICATORS FOR WOOD PRODUCTS IN EXISTING TOOLS

Ideal green building materials are composed of renewable, rather than non-renewable resources and green materials are environmentally responsible because impacts are considered over the life of the product (Spiegel and Meadows, 1999). Depending upon project-specific goals, an assessment of building materials may involve an evaluation in terms of one or more criteria. Generally, the following considerations are key to efforts promoting sustainable design through building material selection. No single material will exhibit all of these characteristics, but designers can strive to choose materials that incorporate as many as possible. Whenever possible, materials should (US Navy WBDG, 2005):

- Not affect indoor air quality adversely;
- Incorporate recycled materials (post-consumer and post-industrial) and/or "biobased" materials from rapidly renewable plant products;
- Be made using natural and/or renewable resources;
- Be durable, and have low maintenance requirements;
- Have low "embodied energy" (the energy required to produce and transport materials);
- Not contain CFCs, HCFCs, or other ozone-depleting substances (ODSs);
- Not contain highly toxic compounds;
- Employ "Sustainable Harvesting" practices, for wood products;
- Be procured from local resources and manufacturers;
- Be reused easily (either whole or through disassembly);
- Be recycled readily (preferably in a closed-loop recycling system); and
- Be biodegradable.

There is a variety of indicators to measure green or sustainable building such as site, energy efficiency, materials efficiency, water efficiency etc. A number of different tools have been developed. Each indicator group consists of different numbers of indicators and indicator systems. Indicators of building and/or building products in existing tools were listed in Appendix A - Environmental indicators for Australian building assessment tools and Appendix B - Environmental indicators for Australian building assessment tools. Of these indicators, some of indicators which are related to wood in existing tools are summarized in Table 13 (see Appendix C - Indicators for wood in existing tools).

Figure 16 shows the contribution rate (%) of the components of the indicators relevant to wood, directly and indirectly, as measured by the maximum possible proportional contribution to the total score which can be achieved in categories and sub-categories where materials, particularly wood products, can influence the result.

Figure 16 shows that evaluation schemes contain indicators which contribute a maximum of about ten percent (with only one exception - EPGB) of total measures which, even indirectly, can be considered as being influenced by materials where wood products are an alternative. Direct measures are almost non-existent with only three ratings schemes containing measures which, at a maximum, contribute a small percent to the total.

Table 13 Indicators that are relevant to wood

Indicator	Unit	Phase	Tool	Relevance to wood
Reuse of façade	%	DSN	Green Star	Indirect
Reuse of structure	%	DSN	Green Star	Indirect
Sustainable timber	%	DSN	Green Star	Direct
Reuse of existing buildings	-	DSN	Green Globes	Indirect
Reuse and recycling of demolition waste	-	DSN	Green Globes	Indirect
Future facilities for recycling	-	DSN	Green Globes	Indirect
There is no asbestos in structure, services, lifts, etc, or where asbestos survey has been carried out and all asbestos either removed or contained and identified within H&S plan	Y/N	DSN	BREEAM	Indirect
Timber for key elements including structural timber, cladding, carcassing, internal joinery is specified to come from sustainably managed sources	Y/N	DSN	BREEAM	Direct
Specifications of timber panel products use only timber that complies with above requirements. This relates specifically to plywood and other composite panel products and to composite timber doors	-	DSN	BREEAM	Direct
There is reuse of > 50% of existing facades	%	DSN	BREEAM	Indirect
There is reuse of > 80% of major structure by building volume	%	DSN	BREEAM	Indirect
Building Reuse	%	DSN	LEED	Indirect
Resource Reuse	%	DSN	LEED	Indirect
Recycled Content	%	DSN	LEED	Indirect
Certified Wood	Y/N	DSN	LEED	Direct
Timber from sustainable forestry	Y/N	P-DSN	CASBEE	Direct
Reuse of existing building structure etc.	Y/N	P-DSN	CASBEE	Indirect

DSN: Design,
P-DSN: Post design

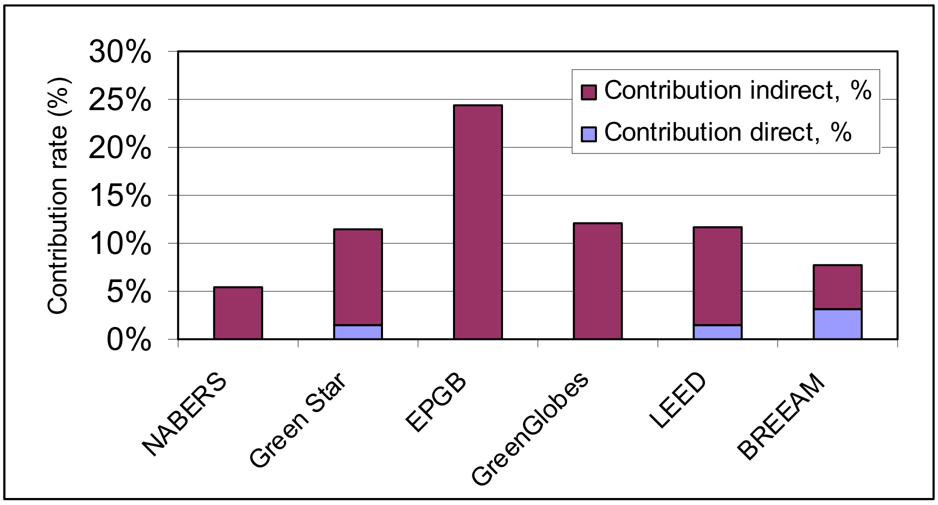

Figure 16 Contribution rate (%) of indicators into the total value in selected tools

Very few of the existing tools have direct indicators related to wood other than wood from managed certified forests. All other advantages of wood are ignored in the indicators. Characteristics of wood products which could/ should be included in the indicators include:

- Being renewable;
- Having lower impact on the environment in terms of embodied energy;
- Having lower impact on the environment in terms of air and water pollution;
- Ease of disposal of waste/recyclability, and
- Carbon storage in long life wood structures.

Relative environmental benefits of materials of any kind (including, concrete, steel and glass) are almost entirely ignored in the assessment and rating schemes investigated with only an occasional indirect influence. The focus on specific measures, such as operating energy, clearly ignores the environmental impact of the embodied energy in materials used to achieve low operating energy (e.g. by mass) and their durability and recyclability when used in buildings.

More efforts should be made in having the environmentally beneficial and whole of life characteristics of the materials used in building included directly in the assessment and rating schemes used to evaluate the environmental performance of buildings.

Recycling of wood products is important in reducing resource depletion impact since non-renewable materials, such as steel, require a high amount of energy to recycle. Steel used for structural purposes also requires a high proportion of virgin metal to maintain certain properties. The renewability of wood and its low manufacturing energy requirements should make it high on the list of choices for communities and homeowners concerned about the careful use of resources.

In summary, despite the advantages described above, existing tools for buildings or building materials comprise very few indicators related to wood (or other materials). Even where indicators which are considered indirectly relevant to wood, are included, they could be as relevant to the choice of non-wood related materials and products as they are to wood. This is because they are mainly performance based indicators for building designers or developers to assess the overall performance of buildings.

The available indicators are not holistic and do not show the full range of environmental benefits of wood products. As a building product, wood has always been included in environmental assessments but usually with limited information and unknown assumptions while a number of non-wood products suppliers and manufacturers are providing detailed information on environmental impacts of their products. Thus, building designers and developers do not often have accurate information to determine when wood is a superior environmental or a competitive choice.

TESTING EXISTING EVALUATION TOOLS

In order to understand the quantitative impacts of using wood products as alternatives to other construction materials in evaluation tools, four tools were applied to Australian domestic houses. The quantitative testing focussed on residential development, since the most common wood products (such as structural timber framing and plywood) are more widely used in residential building compared to commercial buildings in Australia. The four tools were:

- NABERS
- NatHERS
- LCADesign, and
- LISA.

A typical example house was used for the first three tools and an example house provided with the LISA software program was used for the last test.

Description of example house

A typical suburban family dwelling house was selected as an example house (EH). The house was a typical house in Queensland having a floor area of 194 m^2 in a single storey with several wood components (see Figure 17). In this report, it is referred to as the example house (EH). The general information for the example house is shown in Table 14. For further information on the example house see Appendix D - Information on example house for case study.

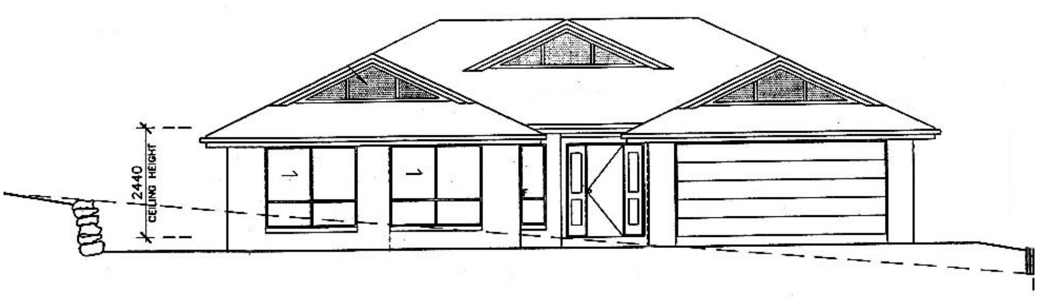

Figure 17 Example house for testing

Table 14 General information for the example house

Information	Amount	Note
Frame	-	Timber Frame
Wall type	-	Brick Veneer Wall
Total land area (sq. metre)	725	Single storey brick veneer on slab, tiled roof.
Total floor area (sq. metre)	194	4 bedrooms, 2 bathrooms
Pervious surfaces (sq. metre)	435	Garden (200 sq. m), Lawn (235 sq. m)
Occupancy (person)	4	2 adults and 2children

* see Appendix D - Information on example house for case study

Selection of the alternative house

For most building designers it is more useful to think in terms of building elements and assemblies, such as a brick veneer wall, which contains bricks, mortar, ties, timber, plasterboard and insulation, rather than individual materials. This allows comparisons of the alternatives which can be considered rather than an assessment of all the individual materials used.

An alternative house (AH) design was selected as having different external wall systems. Several external wall systems are commonly used in Australia for domestic dwelling construction. Of these, Timber Frame Brick Veneer Wall (TFBV) and Timber Frame Weatherboard Wall (TFWB) are very commonly used for the external walls with Autoclaved aerated concrete Block Wall (ABW) being another alternative. Thus, the three external wall assemblies were chosen for the alternative house (AH) to show how existing tools can be used to analyse the environmental impacts of the materials used in the example house and how the impacts could be reduced to become a fundamentally more environmentally sustainable house, based on the plan of the example house. The selected alternatives are shown in Figure 18.

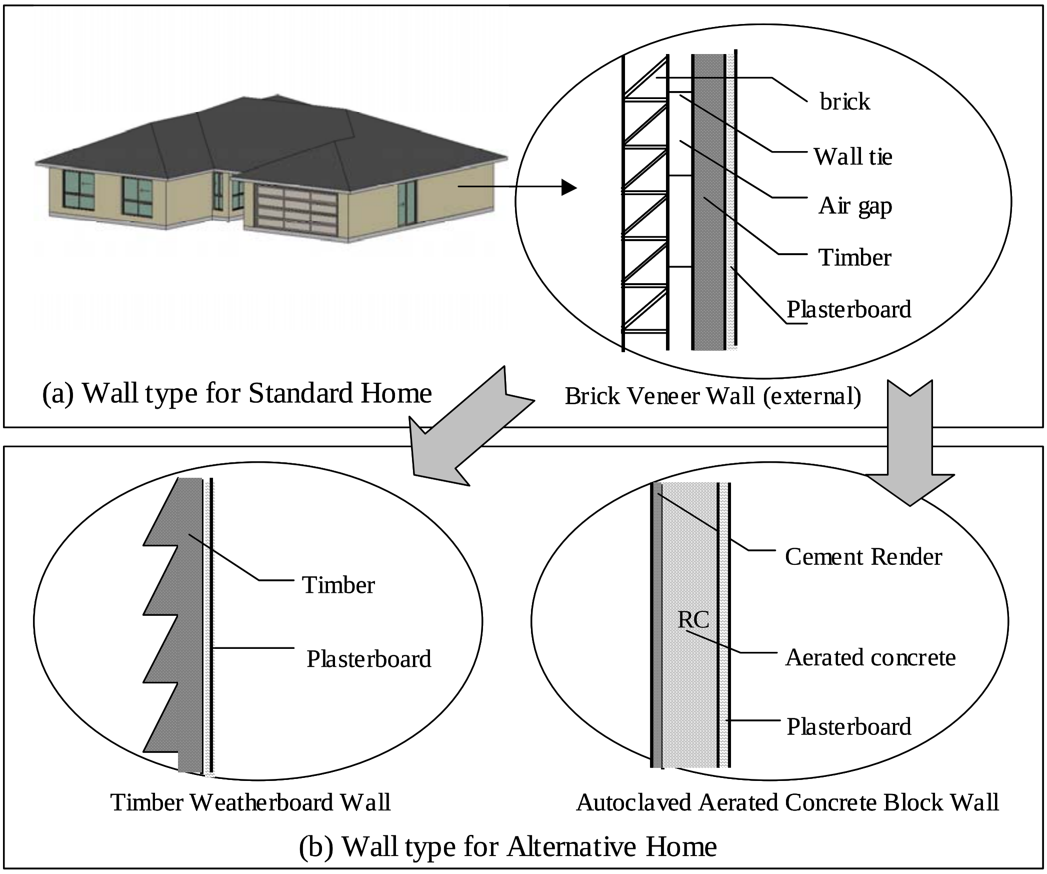

Figure 18 Specification for of alternatives for external wall of standard house

Components for each alternative are summarized in Table 15. One square metre (m^2) of external wall is used in each alternative as the basis of comparison.

Table 15 Amount of main materials required for each external wall alternatives

Example House (EH)		Alternative House (AH)			
Timber Frame Brick Veneer Wall (TFBV, m^2)		Timber Frame Weatherboard Wall (TFWB, m^2)		Autoclaved aerated concrete Block Wall (ABW, m^2)	
Component	Quantity (units)	Component	Quantity (units)	Component	Quantity (units)
Softwood studs	2.6 (lm)	Softwood studs	2.6 (lm)	AAC blocks	1.0 (m^2)
Softwood plates	1.0 (lm)	Softwood plates	1.0 (lm)	External render	1.0 (m^2)
Softwood noggings	0.4 (lm)	Softwood noggings	0.4 (lm)	Plasterboard	1.0 (m^2)
Brick veneer	1.0 (m^2)	Timber weatherboards	1.0 (m^2)	Paint	1.0 (m^2)
Mortar	1.0 (m^2)	Aluminium flashing	0.5 (lm)	LCE*	516 (MJ)
Aluminium flashing	0.5 (lm)	Poly dpc	0.5 (lm)		
Poly dpc	0.5 (lm)	Sarking	1.0 (m^2)		
Wall ties	1.0(each)	Insulation	1.0 (m^2)		
Insulation	1.0 (m^2)	Plasterboard	1.0 (m^2)		
Plasterboard	1.0 (m^2)	Paint	2.0 (m^2)		
Paint	1.0 (m^2)	LCE*	211(MJ)		
LCE*	561(MJ)				

* LCE: Life cycle energy (life span is assumed as 80 years) (Lawson, 1996)

As seen in Table 15, the wall of the TFBV is 2.7 times more energy intensive than the wall of the TBWB alternative during their life cycle (80 years), mainly due to the timber cladding replacing the brick of the example house. But the TFWB house requires twice as much paint over its life, which might produce more of a negative impact on the environment. In terms of material requirements, the ABW alternative requires fewer components compared to others but, as with all the performance based assessments, it is the minimum impact over the whole life cycle which determines the outcome with the lowest impact. However, the wall of the ABW house has a much higher life cycle energy than the wall of the TFWB house.

Applying selected evaluation tools

Case of NABERS

NABERS (the National Australian Built Environment Rating System) is a performance-based rating system that measures an existing building's overall environmental performance during operation.

NABERS rates a residential house on the basis of its measured operational impacts – such as energy, refrigerants (greenhouse and ozone depletion potential), water, stormwater runoff and pollution, sewage, landscape diversity, transport, indoor air quality, occupant satisfaction, waste and toxic materials. NABERS was applied to the example house (EH).

For the case study houses, Figure 19 and Figure 20 show the results for the example house and the alternatives, respectively (see Appendix E - NABERS Data Sheet for more detailed NABERS assessment process). As seen in Figure 19 and Figure 20, overall and detailed scores for both the example house and the alternative houses are all the same having 4.0 points of a possible measurement of total 10 points, which represent a lower than average performance.

A comparison for NABERS results between the example house and alternatives is shown in Figure 21 where the higher the value the better the performance. The results in Figure 21 show that the choice of wall type is effectively irrelevant (assuming the walls have the same thermal performance). Any differences in manufacturing the materials used is ignored. Thus NABERS is not able to differentiate between choices of materials.

NABERS Residential Assessment		
Example Home		
Overall NABERS Score:	*4.0/10 representing Lower average performance.*	
Summary Scores		
Greenhouse Score	2.3	
Water Score	4.7	
Site Management Score	2.7	
Occupant Impact Score	2.5	
Overall Score	4.0	
Detailed Scores		
Environmental issue	Score	
Energy/Greenhouse	2.3	..
Transport	2.3	..
Water Use	4.2	....
Stormwater Runoff	5.0	.....
Stormwater Pollution	4.9	....
Sewage Outfall	5.0	.....
Landscape Diversity	1.3	.
Toxic Materials	2.3	..
Waste Total	3.0	...
Waste Landfill	2.0	..
Indoor Air Quality	1.6	.
Occupant Satisfaction	3.4	...

Figure 19 NABERS certificate for example house

NABERS Residential Assessment		
AH (Alternative Home: Timber Frame Weatherboard Wall)		
Overall NABERS Score:	*4.0/10 representing Lower average performance.*	
Summary Scores		
Greenhouse Score	2.3	
Water Score	4.7	
Site Management Score	2.7	
Occupant Impact Score	2.5	
Overall Score	4.0	
Detailed Scores		
Environmental issue	Score	
Energy/Greenhouse	2.3	..
Transport	2.3	..
Water Use	4.2	....
Stormwater Runoff	5.0	.....
Stormwater Pollution	4.9	....
Sewage Outfall	5.0	.....
Landscape Diversity	1.3	.
Toxic Materials	2.3	..
Waste Total	3.0	...
Waste Landfill	2.0	..
Indoor Air Quality	1.6	.
Occupant Satisfaction	3.4	...

NABERS Residential Assessment		
AH (Alternative Home: Autoclaved Aerated Concrete block Wall)		
Overall NABERS Score:	*4.0/10 representing Lower average performance.*	
Summary Scores		
Greenhouse Score	2.3	
Water Score	4.7	
Site Management Score	2.7	
Occupant Impact Score	2.5	
Overall Score	4.0	
Detailed Scores		
Environmental issue	Score	
Energy/Greenhouse	2.3	..
Transport	2.3	..
Water Use	4.2	....
Stormwater Runoff	5.0	.....
Stormwater Pollution	4.9	....
Sewage Outfall	5.0	.....
Landscape Diversity	1.3	.
Toxic Materials	2.3	..
Waste Total	3.0	...
Waste Landfill	2.0	..
Indoor Air Quality	1.6	.
Occupant Satisfaction	3.4	...

Figure 20 NABERS certificate for alternative houses (Timber frame weatherboard and aerated concrete wall respectively)

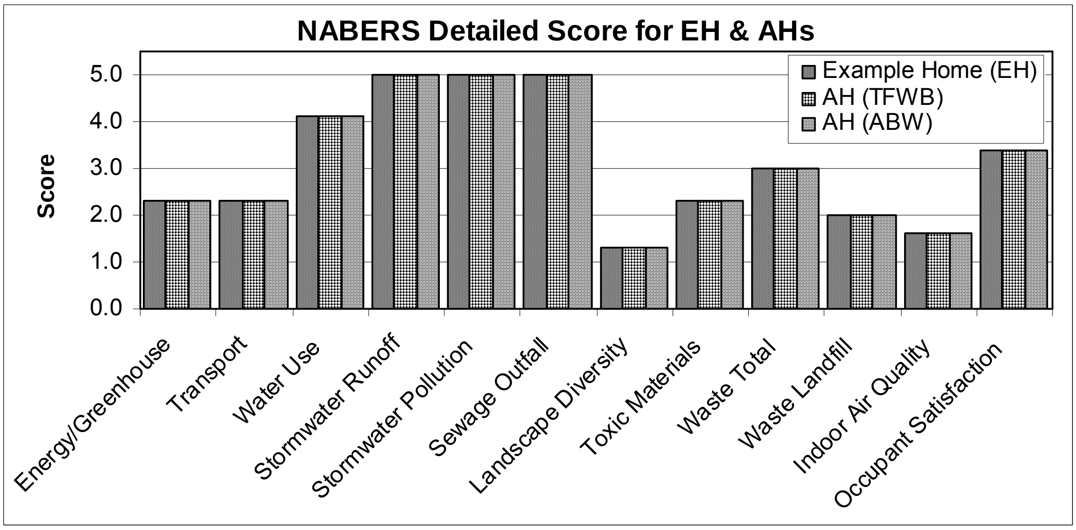

Figure 21 Comparison of NABERS detailed score for example house and alternative houses (Timber frame weatherboard and aerated concrete wall)

Wood products can have both negative and positive environmental effects. The NABERS assessment scheme only appears to produce negative benefits. For example, preservative treatment, which may be needed to enhance the service life for wood products, is assessed in the NABERS questionnaire under the Indoor Air Quality sheet of the NABERS evaluation scheme with a negative attribute.

Other conventional building materials, such as cement or concrete, have a higher impact on the environment. During the construction of a concrete building, for example, 75% of the total energy expended is used in the manufacture of construction materials (Concept Timber Holding, 2004). As shown in Table 15, the timber frame weatherboard wall has less life cycle energy consumption when compared to others (0.4 times less than that for ABW, and similarly for TFBV). In addition, wood is one of the few natural building materials which are reusable. Generally, wood is not toxic, does not leak chemical vapour into the building and is safe to handle and touch. It also means that as wood ages, it does so naturally and does not break down into environmentally damaging materials.

Regardless of these kinds of benefits, the final results from NABERS for the example house and the alternative houses are shown as all being the same which means that no criteria exists in NABERS to reflect any benefits of wood such as less embodied energy, being a renewable material and a carbon store etc.

Case of NatHERS

NatHERS is the leading residential energy rating software in Australia. The Building Code of Australia recognises NatHERS as the primary tool for rating residential designs to ensure they meet the performance based energy efficiency regulations.

The NatHERS software rates the thermal efficiency of a building's envelope and determines the theoretical heating and cooling loads required to maintain interior conditioned spaces within specified comfort levels. Depending on the size of the total heating/cooling load and the climatic zone in which the building is located, NatHERS then assigns a star rating to the building. The star rating is between 0 and 5 stars where 5 stars represents the best performance.

NatHERS simulations were performed on the example house using a variety of wall and floor construction techniques and differing insulation levels. The various combinations were simulated in two climate zones, Melbourne and Brisbane and the results are shown in Table 16.

Table 16 NatHERS results for different alternatives in Melbourne and Brisbane

Floor System		Wall System		Location	Heating	Cooling	Total	Star Rating
Type	Insulation	Type	Insulation					
Conc Slab	None	BV	Foil+R1.5	Melbourne	217.2	30.0	247.2	3.0
Conc Slab	None	BV	Foil Only	Melbourne	238.2	30.8	269.0	3.0
Conc Slab	None	WB	Foil+R1.5	Melbourne	212.7	34.9	247.6	3.0
Conc Slab	None	WB	Foil Only	Melbourne	229.6	36.9	266.5	3.0
Timber	None	BV	Foil+R1.5	Melbourne	250.2	44.9	295.1	2.5
Timber	None	BV	Foil Only	Melbourne	269.7	46.1	315.8	2.0
Timber	None	WB	Foil+R1.5	Melbourne	247.2	51.0	298.2	2.5
Timber	None	WB	Foil Only	Melbourne	263.2	53.8	317.0	2.0
Timber	Styrene	BV	Foil+R1.5	Melbourne	224.7	51.9	276.6	2.5
Timber	R2	BV	Foil+R1.5	Melbourne	200.8	57.0	257.8	3.0
Conc Slab	None	BV	Foil+R1.5	Brisbane	33.1	99.9	133.0	3.0
Conc Slab	None	BV	Foil Only	Brisbane	38.1	103.6	141.7	2.5
Conc Slab	None	WB	Foil+R1.5	Brisbane	33.5	111.5	145.0	2.5
Conc Slab	None	WB	Foil Only	Brisbane	38.4	117.8	156.2	2.5
Timber	None	BV	Foil+R1.5	Brisbane	59.6	140.5	200.1	1.5
Timber	None	BV	Foil Only	Brisbane	64.9	144.6	209.5	1.5
Timber	None	WB	Foil+R1.5	Brisbane	61.3	155.7	217.0	1.5
Timber	None	WB	Foil Only	Brisbane	66.6	163.4	230.0	1.5
Timber	Styrene	BV	Foil+R1.5	Brisbane	55.7	154.1	209.8	1.5
Timber	R2	BV	Foil+R1.5	Brisbane	50.2	164.4	214.6	1.5

Conc Slab: Concrete slab, BV: Brick veneer insulated, WB: Wall with an insulated weatherboard wall

As can be seen in Table 16, the example house (concrete slab, brick veneer, insulated) achieves 3 stars in both Melbourne and Brisbane. Replacing the brick veneer wall with an insulated weatherboard wall sees virtually no change in the overall performance in Melbourne, but does result in a small increase in the required heating/ cooling load in Brisbane (enough to shift the house into the 2.5 star band).

Replacing the concrete slab with a timber floor has a more dramatic impact. In Melbourne, an uninsulated timber floor results in the star rating dropping from 3 to 2.5, regardless of whether it is a brick veneer or weatherboard clad house. In Brisbane the change is even more significant with the uninsulated floor causing the star rating to drop to 1.5 stars. Insulating the timber floor helps improve the performance in Melbourne, but actually has a negative effect in Brisbane. In Melbourne, a timber floor that has an insulated level of R2 will perform as well as a concrete slab and the example house achieves the 3 star rating that the typical brick veneer/concrete slab achieves. The Brisbane results are possibly due to the ability of insulated floors to trap more heat in the house.

The results show that the cooling energy component has increased significantly and this suggests that the higher insulation levels have affected the natural cooling process. These results help to dispel the myth that timber floors can never achieve the same thermal performance as a concrete slab.

Certainly this result might be similar to other regulatory tools such as AccuRate, BERS and Firstrate which address energy efficiency in the form of 'thermal comfort' which is negatively affected by use of timber floors in warmer climates. This type of regulatory tool only considers a part of a building's operational energy (space heating and cooling loads) to the exclusion of other operational energy consumption items and embodied energy which has a positive impact in relation to timber products with a much lower embodied energy that alternatives.

Case of LCADesign

LCADesign (Life Cycle Assessment of Design) is an application/tool which enables building design professionals to make informed decisions on the environmental impact of buildings by providing detailed environmental measures for different materials, products and designs, automatically from their 3D CAD drawings.

LCADesign was created for assessment of commercial buildings, and some modifications were made to enable indicative analyses to be made for some house alternatives. The test was more to demonstrate the potential of life cycle analysis as an assessment method rather than to obtain quantitatively verifiable results.

Figure 22 shows total environmental impact of the example house and alternative houses. The alternative ABW (Autoclaved aerated concrete block wall) has the highest environmental impact among the alternatives being 19.1 ecopoints per square metre of floor area. Compared to the alternative ABW, on the other hand, the example house and alternative TFWB (Timber frame weatherboard wall) have less environmental impact, at 13.8 points/m^2 and 16.0 points/m^2, respectively. Table 17 shows a detailed comparison of each of the alternatives, for a range of indicators, all of which contribute to the total impact measured by Eco-indicator 99. Lower values are better, meaning less environmental impact.

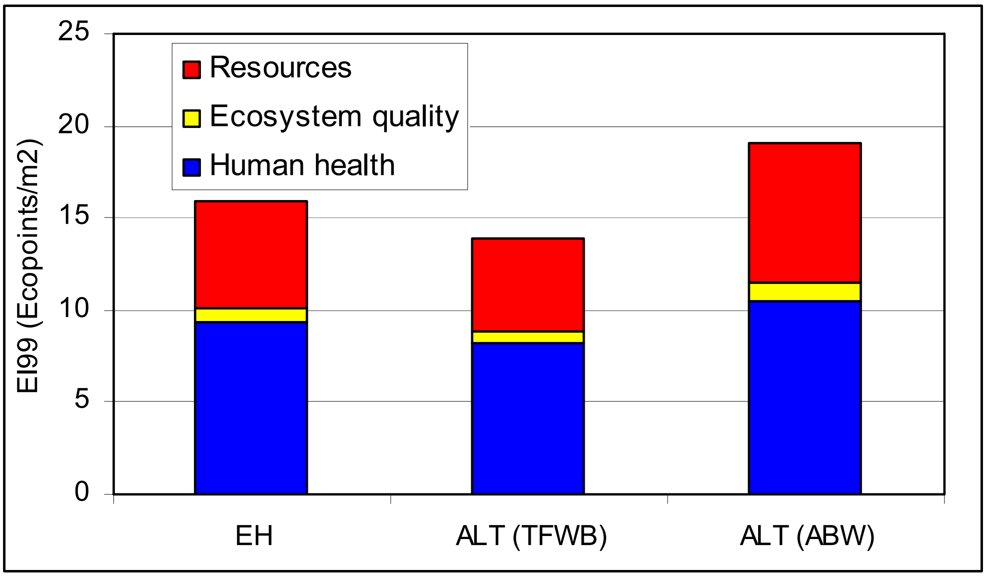

Figure 22 Environmental impact for example and alternative house

Table 17 Different environmental indicators for alternative houses

	EE	EW	GGE	HH	EQ	RS
	MJ	Mega Litre	Kg CO_2 eq.	Ecopoints		
Example House (EH)	2848	3030	270	9.34	0.75	5.88
Alternative (TFWB)	2401	2969	233	8.19	0.67	5.01
Alternative (ABW)	3051	3094	323	10.4	1.01	7.67

TFWB: Timber frame weatherboard wall, ABW: Autoclaved aerated concrete block wall
EE: Embodied energy, EW: Embodied water, GGE: Greenhouse gas emission, HH: Damage to Human health, EQ: Damage to Ecosystem quality, RS: Damage to Resource

Different indicators showed the alternative autoclaved aerated concrete block wall to have the highest impacts for all indicators shown in Table 17. The comparison table for different indicators show that similar results were found in the example house and the alternative TFWB in the human health, ecosystem quality and resources, which is a damage indicator under the Ecoindicator 99 method. Also, the alternative Timber Frame Weatherboard Wall was found to be the best alternative in terms of embodied energy and its corresponding global warming gas emissions.

The results enable evaluation of the environmental impacts of common engineered wood products and systems and comparison of results with selected competing products. In all alternatives, the Timber Frame Weatherboard Wall performed better than the example house (Timber Frame Brick Veneer Wall) when the environmental impact of materials is taken into account.

Case of LISA

LISA (LCA in Sustainable Architecture) is a streamlined LCA decision support tool for construction. Currently, only nominated developers are able to generate case studies, or modify the underlying data or equations in existing case studies. Thus, in this case, a default case building from LISA's database was selected. The case study building is the Fairweather Project home designed specifically for Melbourne climates with the aim of low utilization energy and minimal impact on the surrounding environment.

In this case, the extracted building from LISA's choice of case studies, shown in Figure 23, is referred to as the example house. General information is shown in Table 18.

Figure 23 Example house extracted from LISA database

Table 18 General information for example house for LISA

Information	Note
Life cycle	- 60 years for building - 10 years for appliances - 10 years for fit out
Details	- Timber Frame Pre-fabricated timber stud walls - Single storey reinforced concrete slab, - pre-fabricated Timber roof trusses - Colorbond steel roof - 3 bedrooms Average consumption of Melbourne household - Timber framed windows. - Small upper floor that has timber support - 4 occupants

See Appendix F - Description of Case Study Building for LISA, for more detailed condition

In general, LISA analyses environmental impacts such as resource energy consumption, GGE (greenhouse gas emissions), fresh water consumption, NOx, SOx, NMVOC (non-methane volatile organic compounds) and SPM (suspended particulate matter), on a life cycle basis for building.

Only two simple alternatives were considered because of the limited possibilities for alteration of the LISA database (only a nominated developer can make alterations). The comparison of wood and steel is interesting because the decision to use wood or steel as a building material is made in most design decisions in Australia and such decisions have large implications on the construction materials industry, and also on the environment.

Thus, based on the default house, this example compares wood and steel products for the default house. The Alternative 1 house uses more wood, while the second alternative uses more steel. (see Appendix F - Description of Case Study Building for LISA for more detailed information for case study building).

Figure 24 shows a comparison of environmental criteria for the alternatives. In this figure, the lower the value, the better the performance. As seen in this figure, energy consumption, greenhouse gas, NOx and SPM emissions appear to be higher for the alternative 2. On the other hand, no significant differences are noted for water consumption, SOx and NMVOC emissions.

Table 19 shows more detailed comparison for each of the alternatives. In this case, alternative 2 performs better in all of the criteria especially energy consumption and NMVOC emission.

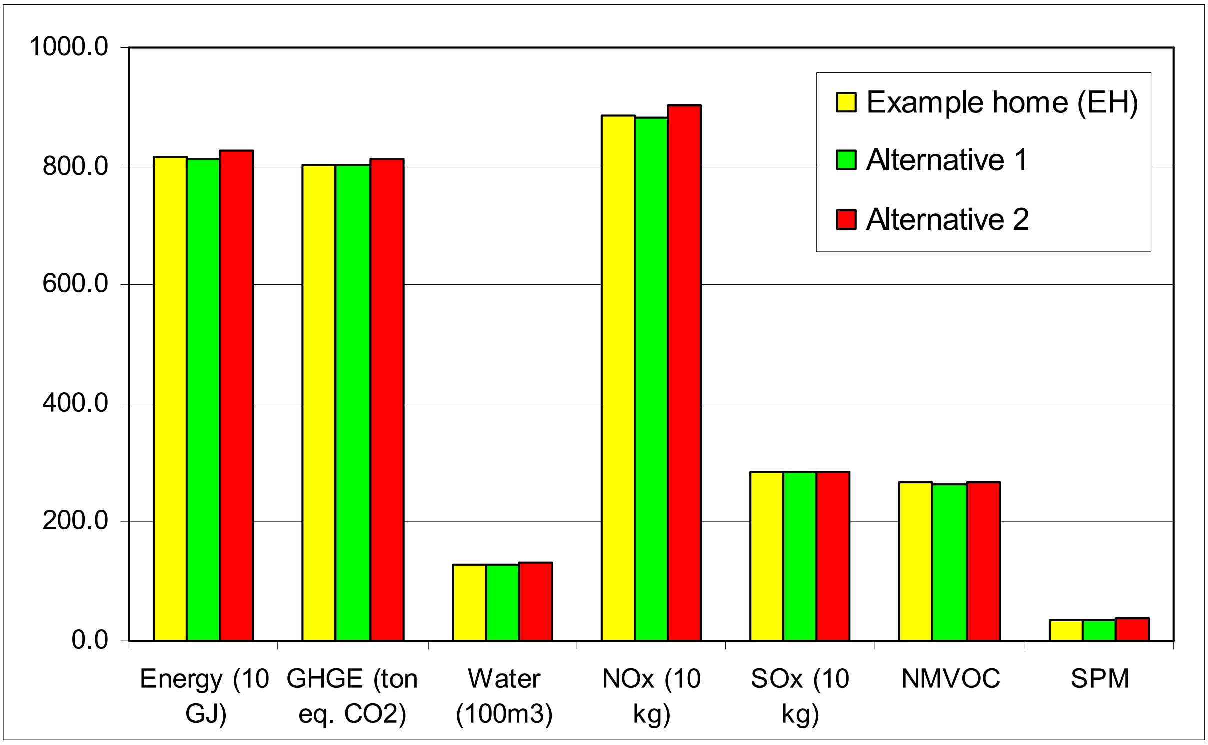

Figure 24 Comparison of results between example house and alternative 1 (timber) and alternative 2 (steel) using LISA

Table 19 Comparison of results between alternatives for whole life cycle

Example house (EH)	CONSTR	APPLIA	FITOUT	UTILIZA	DECOMM	TRANS	SUM
energy (GJ)	268	130	82.2	7730	-53.1	2.01	8159.1
GHGE (ton eq. CO_2)	24.1	8.6	3.51	769	-3.96	0.0204	801.3
Water (m^3)	66.2	73.6	85.1	12800	-10.3	0.00186	13014.6
NOx (kg)	382	71	10.3	8440	-51.7	0	8851.6
SOx	43.3	130	63.7	2620	-15.1	0	2841.9
NMVOC	44.5	36.6	58.9	142	-14.7	0	267.3
SPM	28.9	5.05	1.27	0	-1.53	0	33.7
Alternative 1	**CONSTR**	**APPLIA**	**FITOUT**	**UTILIZA**	**DECOMM**	**TRANS**	**SUM**
energy (GJ)	259	130	82.2	7730	-50.2	2.35	8153.4
GHGE (ton eq. CO_2)	23.5	8.6	3.51	769	-3.76	0.0238	800.9
Water (m^3)	65.3	73.6	85.1	12800	-9.9	0.00217	13014.1
NOx (kg)	376	71	10.3	8440	-49.4	0	8847.9
SOx	42.7	130	63.7	2620	-15	0	2841.4
NMVOC	41.2	36.6	58.9	142	-13.9	0	264.8
SPM	28.9	5.05	1.27	0	-1.51	0	33.7
Alternative 2	**CONSTR**	**APPLIA**	**FITOUT**	**UTILIZA**	**DECOMM**	**TRANS**	**SUM**
energy (GJ)	433	130	82.2	7730	-124	2.36	8253.6
GHGE (ton eq. CO_2)	38.6	8.6	3.51	769	-10.2	0.0239	809.5
Water (m^3)	116	73.6	85.1	12800	-30.1	0.00218	13044.6
NOx (kg)	660	71	10.3	8440	-167	0	9014.3
SOx	64	130	63.7	2620	-23.9	0	2853.8
NMVOC	44.8	36.6	58.9	142	-15.3	0	267.0
SPM	32.4	5.05	1.27	0	-2.37	0	36.4

CONSTR: Construction, APPLIA: Appliances, UTILIZA: Utilization, DECOMM: Decommissioning, TRANS: Material Transport

Summary

Four tools were applied to Australian domestic houses to understand the quantitative environmental impacts of using wood products as alternatives to other construction materials.

Two tools focused on the operation of buildings (i.e. NABERS and NatHERS) while the other two tools (LCADesign and LISA) focus on the life cycle assessment of the materials used in the houses. The conclusion to be drawn from these limited tests is:

- The results from NABERS for the example house and the alternative houses were found to be the same which indicates that no significant criteria exists in NABERS to reflect any benefits of alternative materials such as wood in having less embodied energy, being more environmentally friendly, a renewable material, acting as a carbon store etc.
- Operating energy prediction tools addressing energy efficiency in the form of ‘thermal comfort’ (regulatory tools such as AccurRate, BERS and Firstrate) have a very narrow focus for determining the environmental impact of buildings and ignore any positive impact (operating energy) in relation to capital energy of alternative materials.
- Insulating timber floors increases the calculated cooling energy component significantly and this suggests that the higher insulation levels have reduced the natural cooling process, but, in doing so, it shows that timber floors can achieve the same heating thermal performance as a concrete slab.
- Assessment tools, which are based on the life cycle of building (e.g. LCADesign and LISA) can support the choice of materials on a very broad range of environmental impact grounds with the Timber Frame Weatherboard Wall performing better than the example house (Timber Frame Brick Veneer Wall) and the other alternative house (Autoclaved aerated concrete block wall) when all the environmental impact of materials is taken into account.
- On the whole, existing tools currently do not address the specific attributes of materials such as wood nor do they give any explanation of results or suggestion as to why some results may be higher or lower.
- In the case of wood this can be significant as information regarding wood products and processes is not available in terms of whole of life environmental impacts.

INFORMATION FOR TOOLS FOR WOOD PRODUCTS

Benefits of wood products

Information reflecting the benefits of wood products is important because the decision to use wood instead of alternative products is made many times during design in Australia and such decisions have large implications on the construction materials industry, and thus on the environment.

In general, wood products can be considered as green building materials because they have a unique combination of environmental benefits, being:

- Natural, organic and non-toxic;
- Recyclable, biodegradable and waste efficient;
- Renewable (wooden building materials can substitute items produced from non-renewable fossil materials);
- Effectively carbon-neutral material (even allowing for transport);
- Carbon storing (in wood products in buildings and land fill);
- Sustainable (using recognised harvesting principles and forest management techniques); independent third party certification can be used to identify wood from well managed forests; and
- Low embodied energy (converting wood into a usable building material takes far less energy and generates far fewer greenhouse gases than any other mainstream alternatives, including aluminium, steel and concrete).

Shortcomings

Wood products also have a range of negative impacts such as:

- Short term ecosystem damage and greenhouse gas emission due to disturbance and transport when harvesting and extracting;
- Some low-durability species require preservative treatment to enhance their service life to satisfy code specifications such as Australian Standards;
- Need to segregate contaminated wood in recycling after the product has finished its useful life; and
- Need for some form of maintenance (e.g. paint) requiring repetitive applications for maximal protective effect.

These perceived disadvantages impact on the image of wood products, and thus, can influence customers' decisions on what kind of end products to acquire. These disadvantages may lead to wood products facing strong competition from substitute materials, such as plastics, concrete, steel glass or aluminium, as these materials appear to offer wider options to the customers, even though they may be less environmentally friendly over their whole life.

Conflicting views exist in regards to the environmental consequences of using wood products. On the other hand, a wide range of producers and consumers are aware of the positive environmental aspects of using wood. Scientifically evaluated and verified information needs to be obtained in order to highlight the advantages and disadvantages of using wood products. Unfortunately, the wood industry lags behind other materials industries, such as the steel industry, in conducting environmental, and more specifically, life cycle research and life cycle assessment (LCA), in Australia.

Identification of adequate tools

The tools reviewed can be used to assess environmental impacts over a buildings' life cycle, from materials used to a whole of life cycle approach. Furthermore, each of the individual tools addresses different aspects of a building's environmental impacts. Their coverage also varies from building components to whole of building construction for some of the Australian tools (see Table 1 to Table 6 for comparisons of tools used world-wide).

Most of the tools have limitations and weaknesses and in a recent review of such tools many common problem areas have been identified (Seo, 2002). The problems included having a narrow focus, lacking in-depth assessment, needing professional assessors, requiring time-consuming data input, considering minimal economic criteria and lacking transparency in weighting environmental indicators (Todd *et al.*, 2001). No one model available in Australia completely satisfied all criteria considered in the study or is ever likely to cover all aspects.

The approaches vary greatly. For example, the limitations of the GBTool include it being a framework which is more time consuming than others as it requires users to use other tools to simulate energy performance, estimate embodied energy and emissions, thermal comfort and air quality, etc (Seo, 2002). The GBTool is used to assess pre-occupancy performance as well as occupied building performance. Cole and Larsson (1997) pointed out limitations of the LEED and BREEAM models that include the difficulties in simplification as they are not structured to handle different levels of assessment. Also they were not explicitly designed to handle regional-specific issues, i.e. national or regional variations.

Although some models included criteria such as commuting transport (GBTool, GreenStar and NABERS), almost all tools concentrated on assessment of a building. The exceptions were BEES and Eco-quantum which focused on building products. Seo (2002) suggested that it was important to extend models such as GBTool and LEED to cover community level assessments, as in GreenStar and NABERS, where broad coverage was a goal.

While all real-world design/assessment decisions consider economic aspects alongside other objective criteria, only BEES and LCAid address economic topics. Most models emphasise environmental loadings such as global warming, indoor air quality, energy consumption and resource depletion. As expected of rating schemes, the checklists in these models are fixed so they cannot be modified by regional differences or users' concerns.

The benefits for wood products are not adequately reflected in the existing tools and in many tools would not be expected to be due to the particular focus of the assessment or rating tool. Most building evaluation regulatory tools are based on calculations of the energy efficiency of the completed building or measure the comparative thermal performance of the building envelope.

No assessment or rating tool is ideal or comprehensive and the following couple of examples illustrate this. No significant differences, for example, appeared in the NABERS results in testing existing evaluation tools because NABERS does not cover the design or construction stage for buildings. In spite of the benefits identified for wood products or any other construction materials for that matter, NABERS does not directly reflect construction issues. NatHERS, while a design tool for operational energy minimization, does not consider any properties of materials other than those relating to thermal performance. A common failing with such systems at present is minimal evaluation of the actual materials selected for construction and their environmental impact during the production phase.

All tools reviewed provided for environmental assessment over the building life cycle to some degree to assist users to become more familiar with such concepts. However, the tools could be improved by addressing the following general shortcomings:

- Lack of clarity in what the tool can be used for (e.g. buildings, community, products, energy, eco-indicator, greenhouse gas emissions etc),
- Inability to assess comparisons of alternatives directly to inform choices,
- Need for especially educated assessor even for preliminary assessments,
- Time-consuming effort to obtain and input data,
- Lack of simple parameter settings to apply to Australia as a whole or regions,
- Non-availability of essential economic information, and
- Not showing weightings that can mislead for some applications.

These shortcomings significantly impact on the use of wood products in buildings. For example, the lack of scientifically defined data for wood in existing tools has led to many assumptions, and inappropriate results for wood products may be produced. Also, misinformed comparisons of alternatives may be based on inadequate information and thus negative perceptions for wood. Additionally, users with very limited knowledge of wood might read tool information inadequately and utilise tools incorrectly, which can consequently lead to negative perceptions of wood products.

Thus, evaluation tools are expected to have the following characteristics:

- Ease of use and understanding;
- Readily obtainable input data;
- Clear objective on what is being measured;
- Specific factors e.g. energy, CO_2, or total environmental impact;
- Transparency in components;
- Single value with drill down or profile capacity;
- Quick (or automatic) calculation of measures; and
- Cost impacts.

Due to the growing awareness of building environmental impact, there are increasing demands for green buildings and accordingly, green products. To answer this question of *How to evaluate green buildings or products?* It is necessary to make decisions with evaluation tools, and ensure the tools function as required.

Also, we need to answer questions such as *What are the relevant measures for Green or Sustainable products? How do they apply to our buildings or products?* and *Which evaluation tool is adequate for the intended purpose?*, particularly when the goals may vary widely from energy efficiency to green to sustainable buildings with conflicting requirements.

Relevant measures are still being determined, and those indicators relevant to wood, or other building products, need to be determined through better understanding of whole of life material issues. In terms of selecting the most appropriate tool, few address the issues of material selection, and thus selection can only be based on those procedures represented in Figure 25. Building or product evaluation tools provide differentiation at levels and impacts of interest to the decision maker. Currently a number of tools are available to aid the planning, design, evaluation and management of buildings or building products shown in Table 20. These tools are useful if we select an appropriate tool. The level of detail and accuracy of these tools, however, varies considerably and coverage of environmental factors varies from the specific to total impact. Thus, this variety of tools has the potential to confuse designers and/or project stakeholders.

Table 20 Intended users and life cycle stages for tools

<table>
<tr><th rowspan="2">Intended users and beneficiaries</th><th colspan="3">Intended phase of application</th></tr>
<tr><th>Strategic planning and Schematic design</th><th>Detailed design and construction</th><th>Operation including repair and maintenance</th></tr>
<tr><td>Clients
Asset owners
Providers
Suppliers</td><td colspan="2">Methods for environmentally conscious design
Comparison of possible design alternatives
Assessment against stated target values
Communication between client and designers
e.g. LCADesign</td><td></td></tr>
<tr><td>Owners, investors, occupants
Facility managers, building operators
Developers
Real estate brokers</td><td></td><td colspan="2">Methods for rating existing building from environmental aspect
Communication between stakeholders for investment to existing building
e.g. LEED</td></tr>
<tr><td>Owners
Designers
Building managers and operators
Occupants</td><td></td><td></td><td>Methods for sustainable operation
Communication between stakeholders for building assessment
e.g. NABERS</td></tr>
</table>

There are differing information requirements for the environmental indicators provided for decision support, i.e. what type of information needs to be presented, which type of indicators can users best cope with, and which tool is the most appropriate for decision making. There are differing application requirements for the environmental indicators provided for decision support.

Therefore, it is necessary to understand what decision is being made and choose the appropriate measure and identify the right tool for a project at the right stage of the process and for a specific purpose. Building or products evaluation tools should be selected whether a tool covers intended evaluation criteria after deciding the target (building, product, or parts of building etc.) under the intended phase. This procedure can be summarized in Figure 25.

If goals and decisions are not well understood, information limited, and appropriate tools not determined, the selected building evaluation tool will not be able to:

- Produce relevant environmental information for wood products;
- Deliver right decision making concerning the development of processes and products;
- Compare or select environmentally friendly constructions; or
- Verify environmental criteria.

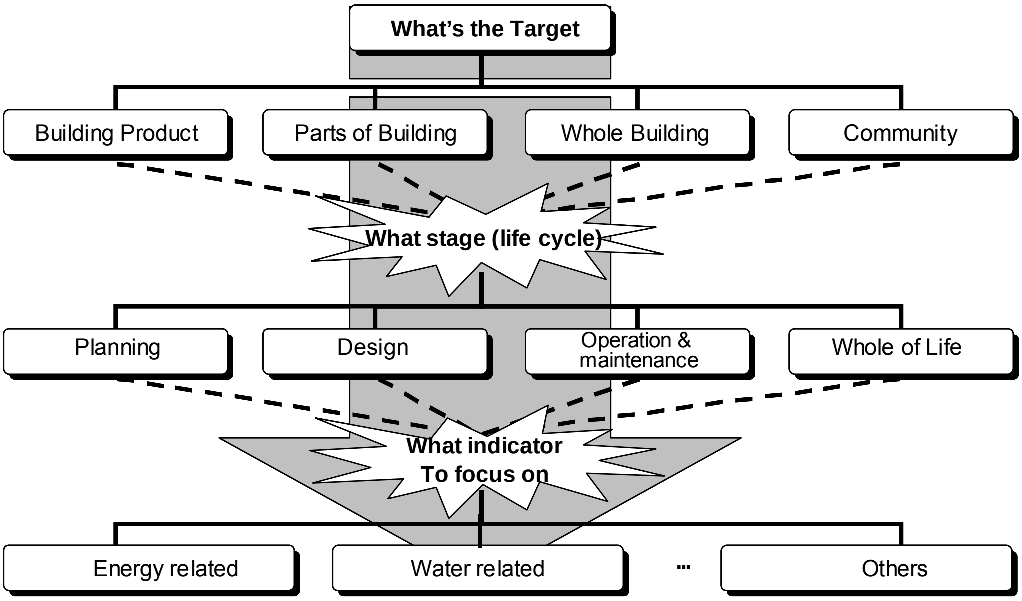

Figure 25 Selection of criteria for building/building assessment tool

CONCLUSION

A wealth of information and tools are available to assist designers or builders in incorporating sustainable technologies and design strategies in their projects. In relation to existing tools, this report presented a short description of the characteristics for a number of evaluation tools which are used for building and building materials, nationally and internationally. In addition, the environmental indicators used in these tools were specifically evaluated for their ability to respond to choice of materials.

The review of existing tools revealed that:

- The evaluation tools generally cover the building level, based on some form of life cycle assessment database except for Ecospecifier and Evergen in the Australian tools list and BEES and Ecoquantum for non-Australian tools which focus on the characteristics of building products rather than the performance of the whole building or element assembly.
- The tools can be categorised as either **assessment** tools (LCAid, LCADesign, LISA, ENVEST, ATHENA EIE, Ecoquantum, Ecoprofile, BEAT, GreenCalc, BEES and EQUER) which provide quantitative performance indicators to help make decisions on design alternatives or **ratings** tools (NABERS, GreenStar, EPGB, BASIX, ABGR, Ecospecifier, Evergen, NatHERS, AccuRate, BERS, Firstrate, GBTool, BREEAM, Green Globes, LEED and CASBEE) which determine the performance and level of a building, against agreed (often subjective) standards, often measured in stars.
- Most of tools listed are voluntary in nature except for BASIX (which is compulsory in NSW for residential building) and NatHERS (or FirstRate) (which is used for regulation for thermal efficiency).
- Current tools mainly assess building performance with little recourse to material indicators.
- Many tools (such as NatHERS, FirstRate, BERS, AccuRate used as regulatory tools) only consider a limited part of building's operational energy (heating and cooling) rather than life cycle energy to the exclusion of other operational energy consumption items and embodied energy to the disadvantage of wood products which have a lower embodied energy than commonly used alternatives.
- Some tools (BASIX and NABERS) draw upon these same narrowly focussed evaluation tools to input data (such as NatHERS for BASIX and ABGR for NABERS) and indirectly overlook characteristics which may benefit wood.
- While wood products can have both negative and positive environmental effects, there are more commonly negative environmental effects rather than positive included. For example, preservative treatment, which may be needed to enhance the service life for wood products, is assessed in the NABERS questionnaire with a negative attribute with no recognition of low embodied energy or renewable attributes.
- Since most assessment and rating tools are based on overall performance, any differences in manufacturing the materials used do not affect the decisions with the result that the schemes are almost entirely unable to differentiate between choices of materials except for indirect consequences.
- Most of the tools had no direct indicators which are specifically relevant to the wood industry with the result that there are few tools which reflect the issues of wood products.

- Most tools are developed for use of building designers/developers to assess their building or building materials and almost none of them are relevant to manufacturers/suppliers.
- Only a few tools concentrate solely on assessing or rating performance in the operating years post-construction (NABERS and ABGR) but several are used in the design stage with evaluations focussed on one aspect (energy) of the operational performance of the building or building product (Accurate, BERS, Ecospecifier, FirstRate, NatHERS, and Green Globes).
- All the tools listed above are intended to document an integrated assessment at the overall project level, usually for new buildings. To perform these assessments, baseline and actual building performance for energy consumption, embodied energy and other performance levels need to be determined using analysis and design tools.

In relation to indicators for existing tools, it was found that:

- Most tools comprise a number of prerequisites and credits with specific design and performance criteria.
- Most tools focus on the material/resource, energy, water, indoor environment quality (IEQ), environmental loadings, of building design and life cycle performance.
- The most optimistic influence on indicators which can be achieved by choice of materials, both directly and indirectly, across all evaluation schemes was a maximum of about ten percent of the total measures with direct measures having almost no influence with only very few ratings schemes containing direct measures which, at a maximum, contribute a few percent to the total.
- Very few of the existing tools have direct indicators related to wood other than wood from certified forests while ignoring advantages of wood such as being renewable, having lower impact on the environment in terms of embodied energy, having lower impact on the environment in terms of air and water pollution, ease of disposal of waste/recyclability, and carbon storage in long life wood structures.
- Advantages of wood products, such as their renewability within the biological ecosystem, are not specifically addressed (except for EQGB in Australia and LEED in North America) even though many tools include recycling as a matter of environmental benefit.
- Manufacturers require ‘building related environmental indicators’ for assessing products in terms of whole-of-life but there are few indicators in the existing tools for the manufacturers to target to improve their products.
- More efforts should be made in having the environmentally beneficial and whole of life characteristics of the materials used in building included directly in the assessment and rating schemes used to evaluate the environmental performance of buildings.
- Even where indicators which are considered indirectly relevant to wood are included, the indicators could be as relevant to the choice of non-wood related materials and products as they are to wood.
- The available indicators are not holistic and do not show the full range of environmental benefits of wood products.

A limited number of tools were tested on an example house and alternatives. From the analysis of these tools it was determined that:

- The tools tested do not adequately reflect benefits of alternative materials (less embodied energy consumption, renewability, carbon storage etc.) since they focus on building performance (i.e. NABERS and NatHERS).
- Operating energy prediction tools addressing energy efficiency in the form of 'thermal comfort' (regulatory tools such as AccurRate, BERS and Firstrate) have a very narrow focus for determining the environmental impact of buildings and ignore any positive impact (operating energy) in relation to capital energy of alternative materials.
- Since the choice of materials, including wood, has little or no influence on whether a building is classed as green or sustainable due to the lack of indicators reflecting environmental advantages of different building material options, specifiers are given little reason for choosing wood over alternative products.
- Assessment tools, which are based on the life cycle of building (e.g. LCADesign and LISA) can support the choice of materials on a very broad range of environmental impact grounds with the Timber Frame Weatherboard Wall performing better than the example house (Timber Frame Brick Veneer Wall) and the other alternative house (Autoclaved aerated concrete block wall) when all the environmental impact of materials is taken into account.
- Assessment of materials should plug into or be a part of whole building evaluation tools but to date the tools investigated do not reflect this and nor do they evaluate wood (or any other materials potentially) adequately.
- Some tools based on life cycle of building, such as LISA and LCADesign, show a better case for wood as the materials of choice on environmental grounds, but they do not address all benefits of materials such as wood.
- Some issues relevant to wood which may make significant difference to the environmental sustainability of a project were identified and how these relate to current indicators needs to be further understood.
- On the whole, existing tools currently do not address all the specific benefits of materials such as wood nor do they give any explanation of results or suggestion as to why some results may be higher or lower.
- In the case of wood this can be significant as information regarding wood products and processes is not available in terms of whole of life environmental impacts.

There is a lack of adequate information relating to wood derived building products that can currently be incorporated in building evaluation tools, which may be part of the explanation as to why more relevant indicators are not included. There is little verified life cycle information available on forest and wood products, and Life Cycle Inventory (LCI) information for wood products is the least well defined in any current Australian LCI database.

Thus, wood products are at a disadvantage compared to other products, such as steel and concrete, as there is no detailed database to provide strategic insight for use in pro-active environmental marketing, process improvement, comparison for product substitution, and, importantly, to be used to supply information for building evaluation tools. Building designers and material specifiers currently do not have the necessary quality and substantiated information to determine when wood is a superior or competitive choice.

There is an increasing inclusion of issues that are not material specific in the assessment and rating tool indicators which indirectly affect the use of wood products through materials choices. This suggests that the wood industry should establish partnership approaches with other materials suppliers to clarify performance-based building issues relating to materials.

More detailed knowledge of the environmental impacts of wood products and other materials would provide the evidence for revising the tools to include more measures related directly to the choice of material. Life Cycle Assessment (LCA) could be one of the solutions to provide information on the entire product process from forests to disposal, including issues of maintenance, durability, product life, re-use and recyclability. It is this information which can provide a quantitative basis for comparing wood products, their manufacturing processes and, most importantly, from the wood industry point of view, wood-based products performance against competitors who use other resources to create alternative products.

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Appendix A - Environmental indicators for Australian building assessment tools

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
ABGR	Energy/Greenhouse	Normalized emissions	Kg CO_2 eq/m^2/year	O & M	None
NatHERS	Energy	Energy consumption	MJ/m^2*year	O	None
BASIX	Landscape	Total area of vegetation (garden and lawn)	m^2	DSN	None
		Area of indigenous species	m^2	DSN	None
	Storm water	Roof area collected by rainwater tank	m^2	DSN	None
		Rainwater used for toilet/laundry/garden	-	DSN	None
		Tank size	Litre	DSN	None
		Runoff collected from roof area/impervious area/landscape area	m^2	DSN	None
		Storm water used for garden only	-	DSN	None
		Tank size	Litre	DSN	None
	Water	Reticulated recycled water (not rain/storm water)	L/day	O & M	None
		Recycled water used for toilets/laundry/garden	-	O & M	None
		Onsite recycled water system using treated grey water/diverted grey water	-	O & M	None
		Onsite recycled water collected from laundry/bathroom	-	O & M	None
		Recycled water used for toilets/laundry/garden	-	O & M	None
		Toilets rating	average L/flush	DSN	None
		Showerheads rating	-	DSN	None
		Tap fittings	-	DSN	None
		Swimming pool volume	kL	DSN	None
		Swimming pool cover	-	DSN	None
		Volume of outdoor spa	kL	DSN	None
		Clothes washer	-	O & M	None
		Dishwasher	-	O & M	None
	Thermal comfort	Net conditioned floor area	m^2	O & M	None
		Do any concessions apply	-	O & M	None
		Annual cooling load (sensible plus latent)	MJ/m^2*year	O & M	None
		Annual heating load	MJ/m^2*year	O & M	None
		Dwelling is not significantly overshadowed	-	O & M	None
		Total skylight area <2% of gross floor area (Must be Yes)	-	DSN	None
		Primary ground floor construction type and area	m^2	DSN	None
		Secondary ground floor construction type and area	m^2	DSN	None
		Primary external wall type and area	m^2	DSN	T. Yes
		Secondary external wall type and area	m^2	DSN	T. Yes
		Wall shared with adjoining dwelling type and area	m^2	DSN	None
		Wall shared with garage type and area	m^2	DSN	None

DSN: Design, O: Operation, O&M: Operation & maintenance

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
BASIX	Thermal comfort	Ceiling and roof type and area	m^2	DSN	None
		Concessions	-	DSN	None
		Area of all living spaces	m^2	DSN	None
		Area of ventilation openings in living spaces	m^2	DSN	None
		Are openings provided on opposite or adjacent walls in each living space?	-	DSN	None
		Number of bedrooms with 2 or more windows or operable skylights	-	DSN	None
		Glazing frame type	-	DSN	T. Yes
		Glazing type for each orientation (N,E,S,W)	-	DSN	None
		Area of proposed glazing for each orientation	m^2	DSN	None
		Shading type for each orientation	-	DSN	None
		Floor insulation	-	DSN	None
		External wall insulation	-	DSN	None
		Ceiling and roof insulation	-	DSN	None
		Roof color	-	DSN	None
		Roof ventilation	-	DSN	None
	Energy	Living area cooling system type	-	DSN	None
		Bedroom area cooling system type	-	DSN	None
		Living area heating system type	-	DSN	None
		Bedroom area heating system type	-	DSN	None
		Hot water system type	-	DSN	None
		Lighting not specified (Yes/No)	-	DSN	None
		If lighting specified (Yes/No)	-	DSN	None
		Enter rooms primarily lit by standard or compacted fluorescent lamps	-	DSN	None
		Natural lighting to kitchen	-	DSN	None
		Natural lighting to all bathrooms and toilets	-	DSN	None
		Cooking system type (gas/electric etc.)	-	DSN	None
		Pool and spa pump controlled by timer	-	DSN	None
		Pool heating type	-	DSN	None
		Spa heating type	-	DSN	None
		Well ventilated refrigerator space indoor clothes drying line or cupboard	-	DSN	None
		Outdoor clothes drying line	-	DSN	None
		Photovoltaic system	kW peak	DSN	None
		Refrigerator energy star rating	star	O & M	None
		Dishwasher energy rating	star	O & M	None
		Clothes washing energy star rating	star	O & M	None
		Clothes dryer energy star rating	star	O & M	None
BERS	Energy	Thermal performance	MJ/m^2*year	O	None

DSN: Design, O: Operation, O&M: Operation & maintenance

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
EcoSpecifier	Energy & greenhouse gas	Low energy in production	-	MNF	None
		Less GHG/ODP down stream	-	O & M, DSN	None
	Habitat and & degradation	Reduced terrestrial impacts	-	MNF	None
		Reduced aquatic impacts	-	MNF	None
	Resource depletion & efficiency	Abundant material	-	MNF	None
		Post-consumer recycled content	-	MNF	None
		Post industrial recycled content	-	MNF	None
		Extended producer responsibility	-	MNF	None
		Take-back/product stewardship	-	MNF	None
		Reuse potential	-	MNF	None
		Commonly recycled	-	MNF	None
		Ecopackaging (minimize impacts)	-	MNF	None
		Reduced transport energy	-	MNF	None
		Least processed materials	-	MNF	None
		Agricultural by-product	-	MNF	None
		Rapidly renewable product (less than 3 yrs)	-	MNF	None
		Reduced material use	-	MNF	None
	Occupant & contractor health	Low/reduced off gassing	-	O & M	None
		Reduced EMR (Electromagnetic radiation)	-	O & M	None
		Reduced toxic or carcinogens	-	O & M	None
	Toxicity to air, land, water	Reduced life cycle toxicity	-	O & M	None
	Toxicity to land	Reduced life cycle carcinogen	-	O & M	None
	Toxicity to water	Reduced smog	-	O & M	None
	Other vital signs	Having MSDS (Material Safety Data Sheet)	-	-	None
		Ecolabel/certification (ISO/AS 14000)	-	-	None
		Independent LCA	-	-	None
		Independent verification	-	-	None
		Documented manufacturer claim	-	-	None
		Environmental info about product	-	-	None
		Australian standard	-	-	None
		Environmental policy	-	-	None
EPGB	Energy	Energy used to manufacture and construct buildings	MJ/m^2*year	CONS	None
		Energy used to operate buildings	MJ/m^2*year	O & M	None
	Land	Area of land used	m^2 land/m^2 building	DSN	None
	Water	Water used to operate building	m^3/m^2*year	O & M	None
		Water used for landscape	m^3/m^2*year	O & M	None
	Materials	Materials used for initial project construction	% weight or area (2 separate measures)	CONS	None
		Materials likely to be recoverable in future	% weight , volume or cost	CONS	None

MNF: Manufacturing, CONS: Construction, DSN: Design, O&M: Operation & maintenance

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
EPGB	Materials	Renewable resources	% by weight	CONS	Yes
	Greenhouse gas	Emissions of global warming potential material	$KgCO_2/m^2/yr$	O & M	None
	Ozone depleting substances	Emissions of Ozone Depleting Potential substances	-	O & M	None
	Site ecology	Initial ecological value of site	-	CONS	None
		Change in ecological value of the site	-		None
		Restoration of damaged ecosystems	-		None
		Designed landscape	-	DSN	None
	Solid wastes	Construction process wastes	% tonnes, % m^3, whole structure.	CONS	None
		Building operations wastes	% recycling skips/landfill skips	O & M	None
	Liquid effluent	Storm water flows to mains system	m^3 / m^2 *yr	O & M	None
		Sanitary waste flows to mains system	m^3 / m^2 *yr	O & M	None
	Physical impacts	Access to daylight of adjacent property.	degrees	DSN	None
		Overshadowing of adjoining sites	%	DSN	None
		Noise impact mitigation from building	-	DSN	None
		Wind conditions around high buildings	-	DSN	None
		Adverse visual Impacts	-	DSN	None
	Air quality and ventilation	Moisture control	-	DSN	None
		Pollutant source control	-	DSN	None
		Ventilation and fresh air delivery	-	DSN	None
	Thermal comfort	Air temperature	-	DSN	None
		Relative humidity	-	DSN	None
	Lighting	Provision of daylighting	-	DSN	None
		Ambient illumination levels	-	DSN	None
		Visual access to the exterior	-	DSN	None
	Noise	Noise attenuation through the building envelope	-	DSN	None
		Transmission of building equipment noise	-	DSN	None
		Noise attenuation between occupant units	-	DSN	None
	Material harzard	Minimize materials hazards	-	DSN	None
		Sick Building Syndrome (SBS)	-	DSN	None
	Adaptability & flexibility	Ease of adapting technical systems to changing user requirements	-	DSN	None
		Suitability of layout and structure for changes in building uses	-	DSN	None
		Adaptability to future changes in type of energy supply	-	DSN	None
	Maintenance of performance	Access to building elements for maintenance and replacement	-	O & M	None
		Access to technical systems for maintenance and replacement	-	O & M	None

CONS: Construction, DSN: Design, O&M: Operation & maintenance

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
EPGB	Maintenance of performance	Selection of material durability appropriate to planned service life	-	O & M	None
		Protection of materials from destructive elements	-	O & M	None
		Ability to maintain performance under abnormal conditions	-	O & M	None
		Protection from natural disasters	-	O & M	None
	Controllability of systems	Capability for partial operation of building technical systems	-	O & M	None
		Level of building automation appropriate to system complexity	-	O & M	None
	Economics	Life-cycle cost of building	-	LC	None
		Environmental evaluation	-	LC	None
	Management process	Pre-design	-	P-DSN	None
		Design	-	DSN	None
		Construction	-	CONS	None
		Performance tuning	-	O & M	None
		Building operations	-	O & M	None
	Commuter transport	Access to public transport	-	O & M	None
		Facilities for bicyclists	-	O & M	None
		Environmental impact of motor vehicles	-	O & M	None
	Cultural environment	Conservation of cultural heritage	-	O & M	None
		Community facilities	-	O & M	None
		Equity and access	-	O & M	None
Evergen	Energy				None
	Water				None
	IEQ				None
	Material/Resource				None
	Greenhouse gas				None
	ODP				None
	Emission to air				None
	Emission to water				None
	Emission to land				None
	Biodiversity				None
Firstrate	Energy	Thermal performance	MJ/m^2*year	O	None

P-DSN: Pre-design, CONS: Construction, DSN: Design, O: Operation, O&M: Operation & maintenance, LC: Life cycle

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
Green Star	Management	Green star accredited professional	-	DSN	None
		Commissioning - clauses	-	DSN	None
		Commissioning - building tuning	-	DSN	None
		Commissioning - commissioning agent	-	DSN	None
		Building users guide	-	DSN	None
		Environmental management	-	DSN	None
	IEQ	Ventilation rates	%	O & M	None
		Air change effectiveness	-	O & M	None
		CO_2 monitoring and control	-	O & M	None
		Daylighting	%	O & M	None
		Daylight glare control	-	O & M	None
		High frequency ballasts	-	O & M	None
		Electric lighting level	lux	O & M	None
		External views	*m*	O & M	None
		Individual thermal comfort control	%	O & M	None
		Asbestos	-	O & M	None
		Thermal modeling	-	O & M	None
		Internal noise levels	dB	O & M	None
		Indoor air pollutants	-	O & M	None
	Energy	Energy consumption	Kg CO_2 e/m^2	O & M	None
		Energy improvement	Kg CO_2 e/m^2	O & M	None
		Electrical submetering	-	O & M	None
		Tenancy submetering	-	O & M	None
		Office lighting power density	W/m^2/100 lux	O & M	None
		Office lighting zoning	-	O & M	None
		Peak energy demand reduction	-	O & M	None
	Transport	Provision of car parking	%	O & M	None
		Small parking spaces	%	O & M	None
		Cyclist facilities	-	O & M	None
		Commuting public transporting	minute	O & M	None
	Water	Occupant amenity potable water efficiency	Liter/day/person	O & M	None
		Water meter	-	O & M	None
		Landscape irrigation water efficiency	-	O & M	None
		Cooling tower water consumption	-	O & M	None
	Materials	Recycling waste storage	-	DSN	None
		Reuse of façade	%	DSN	None
		Reuse of structure	%	DSN	None
		Shell & core or integrated fitout	%	DSN	None
		Recycled content of structural concrete	%	DSN	None
		Recycled content of structural steel	%	DSN	None
		PVC minimization	%	DSN	None
		Sustainable timber	%	DSN	Yes
	Land use & Ecology	Ecological/ social value of site	-	DSN	None
		Re-use of land	-	DSN	None
		Reclaimed contaminated land	-	DSN	None
		Change of ecological value	m^2	DSN	None

DSN: Design, O&M: Operation & maintenance

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
Green Star	Management	Topsoil & Fill removal from site	-	DSN	None
	Emissions	Refrigerant ODP	%	O & M	None
		Refrigerant GWP	%	O & M	None
		Refrigerant leak detection	%	O & M	None
		Refrigerant recovery	-	O & M	None
		Watercourse pollution	-	O & M	None
		Reduced flow to sewer	L/day	O & M	None
		Light pollution	-	O & M	None
		Cooling towers	-	O & M	None
		Insulant ODP	-	O & M	None
	Innovation	Innovation	-	DSN	None
LCADesign	Resource	Mineral extraction	MJ surplus	LC	None
		Fossil fuel extraction	MJ surplus	LC	None
		Embodied energy	MJ	LC	None
		Embodied water	Mega Litre	LC	None
	Human health	carcinogens	DALY	LC	None
		Respiratory organics	DALY	LC	None
		Respiratory inorganics	DALY	LC	None
		Climate change	DALY	LC	None
		Ozone layer depletion	DALY	LC	None
	Ecosystem quality	Ecotoxicity	PAF/m^2/yr	LC	None
		Acidification & eutrophication	PDF/m^2/yr	LC	None
	Other impact	Embodied carbon dioxide	Ton CO_2	LC	None
		Total greenhouse gases emission	CO_2 eq.	LC	None
		Ecological footprint	Gha	LC	None
		Biodiversity loss	-	LC	None
	IAQ	Indoor air quality	-	LC	None
LCAid	Resource	Energy usage	MJ	LC	None
		Water	kLt	LC	None
	Impact	Greenhouse effect	kg	LC	None
		Ozone depletion	kg	LC	None
		Solid waste	kg	LC	None
		Heavy metals	kg	LC	None
		Nutriphication	kg	LC	None
		Acidification	kg	LC	None
		Carcinogenesis	kg	LC	None
		Summer smog	kg	LC	None
		Winter smog	kg	LC	None
LISA	Energy	Resource energy	TJ	LC	T. Yes
	Water	Total water use	m^3	LC	None
	Global warming	Greenhouse gas emission	CO_2 eq	LC	None
	Emission to air	Total NOx emission	ton	LC	None
		Total SOx emission	ton	LC	None
		Total NMVOC (Non Methan VOC)	kg	LC	None
		Total SPM	kg	LC	None
NABERS	Energy & Greenhouse	Normalized greenhouse gas emissions	Kg CO_2 e/m^2	O & M	None
	GWP	Refrigerant impact		O & M	None
	ODP	Refrigerant impact	R11 e/m^2	O & M	None
	Water	Metered water consumption from all source	m^3/yr	O & M	None

DSN: Design, O&M: Operation & maintenance, LC: Life cycle

Tools	Issue	Indicator	Unit	Phase	Relev. Timber
NABERS	Transport	Public transport type	-	O & M	None
		Distance traveled	km	O & M	None
	Stormwater	Storm water runoff	m^3/yr	O & M	None
	Water pollution	Storm water pollution	-	O & M	None
	Sewage	sewage outfall	m^3/yr	O & M	None
	Landscape diversity	Entire site	m^2	O & M	None
		% Native cover based on the % area	%	O & M	None
		Complexity index	-	O & M	None
	Waste	Weight of total waste	kg	O & M	None
		Weight of waste sent to landfill	kg	O & M	None
	Toxic material	Toxic material presence	-	O & M	None
		Toxic material storage	-	O & M	None
		Disposal of toxic material	-	O & M	None
	IAQ	CO_2 concentration	ppm	O & M	None
		CO concentration	ppm	O & M	None
		Respirable dust	mg/m^3	O & M	None
		Airborne viable bacteria	CFU/m^3	O & M	None
		Airborne fungi & mould	CFU/m^3	O & M	None
		Ozone	ppm	O & M	None
		Formaldehyde	ppm	O & M	None
		Total volatile organic compounds	ug/m^3	O & M	None
		Individual volatile organic compounds	ug/m^3	O & M	None
	Occupant satisfaction	Overall temperature satisfaction	-	O & M	None
		How cold it gets	-	O & M	None
		How hot it gets	-	O & M	None
		Temperature shifts	-	O & M	None
		Overall ventilation satisfaction	-	O & M	None
		Air freshness	-	O & M	None
		Air movement	-	O & M	None
		Draughts	-	O & M	None
		Overall noise satisfaction	-	O & M	None
		Office noise	-	O & M	None
		Noise from air-conditioning and lighting system	-	O & M	None
		Noise from outside building	-	O & M	None
		Overall lighting satisfaction	-	O & M	None
		Level of light at your desk	-	O & M	None
		Glare from lights	-	O & M	None
		Glare from windows	-	O & M	None
		Sore eyes	-	O & M	None
		Headaches	-	O & M	None
		Runny nose	-	O & M	None
		Dry throat	-	O & M	None
		Dry or irrtated skin	-	O & M	None
		Lethargy	-	O & M	None
		Dizziness	-	O & M	None
		Nausea	-	O & M	None
NatHERS	Energy	Thermal performance	MJ/m^2*year	O	None

O: Operation, O&M: Operation and maintenance

Appendix B - Environmental indicators for Non-Australian building assessment tools

Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
ATHENA		Embodied energy		LC	N.A	None
		Global warming potential		LC	N.A	None
		Solid waste emissions		LC	N.A	None
		Pollutants to air		LC	N.A	None
		Pollutants to water		LC	N.A	None
		Natural resource use		LC	N.A	None
BEAT	Impact	Global warming	-	LC	Denmark	None
		Ozone depletion	-	LC	Denmark	None
		Acidification	-	LC	Denmark	None
		Nutrient enrichment	-	LC	Denmark	None
		Ecotoxicity	-	LC	Denmark	None
		Human toxicity	-	LC	Denmark	None
		Persistent toxicities	-	LC	Denmark	None
		Photochemical ozone formation	-	LC	Denmark	None
		Resources, fuels	-	LC	Denmark	None
		Resources, metals	-	LC	Denmark	None
		Hazardous waste	-	LC	Denmark	None
		Slag & ash	-	LC	Denmark	None
		Volume waste	-	LC	Denmark	None
		Radioactive waste	-	LC	Denmark	None
		Resources, minerals	-	LC	Denmark	None
BEES	Impact	Embodied energy	MJ	LC	NA	None
		Global warming	g CO_2 eq.	LC	NA	None
		Acidification	mg H+ eq.	LC	NA	None
		Eutrophication	g N eq.	LC	NA	None
		Fossil fuel depletion	MJ	LC	NA	None
		Indoor air quality	g Total VOC	LC	NA	None
		Habitat alteration	T&E species	LC	NA	None
		Water intake	Liters	LC	NA	None
		Criteria air pollutants	micro DALYs	LC	NA	None
		Ecological toxicity	g 2,4D eq.	LC	NA	None
		Human health	g C_2H_2 eq.	LC	NA	None
		Ozone depletion	g CFC-11 eq.	LC	NA	None
		Smog	g NOx eq.	LC	NA	None
		Environmental performance	pts	LC	NA	None
		Economic performance	pts	LC	NA	None
		Overall performance	PV $	LC	NA	None

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N.A: North America

Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
BREEAM	Management	Evidence can be provided showing a client commitment to a firm commissioning period prior and Immediately post occupation to ensure efficient operation of all services within the building	-	DSN	UK	None
		There is an established and openly available company policy on the environment.This should include the following as a minimum requirement	-	O	UK	None
		There is a verifiable environmental purchasing policy at a corporate level and is demonstrably in Use at a local level	-	O	UK	None
		A verifiable environmental management system (formal or informal) is in operation	-	O	UK	None
		Building operating manuals are available on site	-	O	UK	None
	Health & well-being	Cooling towers locations are designed to allow ease of access to filters/drip trays etc for cleaning/replacement or no cooling towers	-	DSN	UK	None
		Domestic hot water systems have been designed or actions taken to minimise risk of Legionellosis	-	DSN	UK	None
		At least 30% of windows to office areas are openable. This should have an even distribution Around the office area	-	DSN	UK	None
		There is no/steam humidification	-	DSN	UK	None
		Air intakes/outlets are over 10 m apart to minimise recirculation and avoid sources of major External pollution	-	DSN	UK	None
		At least 30% fresh air is provided in a/c mech vent systems or trickle vents are provided in naturally ventilated buildings	-	DSN	UK	None
		At least 80% of net lettable office area is adequately daylight	-	DSN	UK	None
		Controllable internal or external blinds are fitted to prevent glare	-	DSN	UK	None
		High frequency ballasts are installed in all general office luminaries	-	DSN	UK	None
		Lighting meets BCO Specification for Offices recommendations in terms of lighting levels	-	DSN	UK	None
		Control of lighting in office areas relates to circulation space, daylighting and is broken down to provide separate control for groups of no more than four work areas	-	DSN	UK	None
		All workstations have view out with max 7 m to windows	-	DSN	UK	None
		Local control is available for temperature in office areas	-	DSN	UK	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
BREEAM	Health & well-being	Cooling towers/systems are designed in accordance with HSG70 & TM13 or no cooling towers	-	DSN	UK	None
		Assessments have been made of thermal comfort levels at design stages and used to evaluate appropriate servicing options	-	DSN	UK	None
		Design achieving ambient noise levels	dB	DSN	UK	None
		There is an established and operational policy to operate maintenance schedules covering all systems including regular checking of controls, filters and cleaning in compliance with the HVCA Standard Maintenance Specification for Mechanical Services in Buildings	-	O	UK	None
		Safety survey of dhws has been carried out and appropriate steps taken to minimise risks within last three years or building is less than three years old. Where building < 3 years old design to TM13	-	O	UK	None
		Smoking ban is in effect	-	O	UK	None
		Maintenance schedules include high performance cleaning of carpets and soft furnishings with steam or liquid nitrogen cleaning at least once a year	-	O&M	UK	None
		Procedures operate for the collection and recording of occupant feedback and comparisons are made to historical data	-	O&M	UK	None
		Improvement targets relating to occupant satisfaction are in place	-	O&M	UK	None
	Energy	Total net CO_2 emissions	kg $CO_2/m^2/yr$	O	UK	None
		Sub-metering is available for substantive energy uses within the building covering lighting and each of the following where present computer room, catering facilities, humidification plant, cooling plant, and fan.	-	DSN	UK	None
		Check-metering of tenancy areas (in multi-occupant buildings only) or single tenancy	-	DSN	UK	None
		Energy policy is endorsed by Board and available to staff in accordance with GPG 186	-	O	UK	None
		An energy audit of building is carried out at least every three years	-	O	UK	None
		There is quarterly dissemination of information on energy use and savings	-	O	UK	None
		Energy/CO_2 monitoring is carried out using historical data	-	O	UK	None
		Energy/CO_2 targeting is carried out using historical data	-	O	UK	None
		Evidence is available showing movement towards energy/CO_2 targets over time	-	O	UK	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
BREEAM	Health & well-being	Actual energy consumption figures are less than established good practice benchmark levels	-	O	UK	None
		There are established and operational maintenance schedules covering calibration and operation of all heating and cooling system controls. Full maintenance records should be available	-	O	UK	None
		There are established and operational maintenance schedules that cover regular cleaning of lighting installations (at least every two years) and phased replacement of luminaries in line with best practice. Full maintenance records should be available	-	O	UK	None
	Transport	Total net CO_2 emissions arising from transport too and from the building will be predicted based on location.	-	DSN	UK	None
		Public transport connections are GOOD and car parking in the area is restricted by at least 20% from the LA standard	-	DSN	UK	None
		Provision of cycling facilities: Sheds, Showers and changing facilities	-	DSN	UK	None
		Policies and actions taken to encourage the use of public transport for commuting to and from the site (passes/loans etc) and to discourage the use of the private car	-	O	UK	None
		Policies and actions have been taken to encourage the use of public transport and to discourage the use of the private car for business travel	-	O	UK	None
		Good access to public transport networks within 500 m and with a 15 min service frequency to local urban centre	-	DSN	UK	None
		Good access to public transport networks within 500 m and with a 30 min service frequency to major transport node	-	DSN	UK	None
	Water consumption	Predicted water consumption	$m^3/d/p$	DSN	UK	None
		A water meter is installed to all supplies to building	-	DSN	UK	None
		A leak detection system is installed covering all mains supplies	-	DSN	UK	None
		A proximity detection shut off is provided to water supply in toilet areas	-	DSN	UK	None
		There are established and operational maintenance procedures covering all water systems, taps, sanitary fittings and major water consuming plant. Full maintenance records should be available.	-	O&M	UK	None
		Water consumption monitoring is carried out at least once every quarter using historical data	-	O&M	UK	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
BREEAM	Health & well-being	There is no asbestos in structure, services, lifts, etc, or where asbestos survey has been carried out and all asbestos either removed or contained and identified within H&S plan	-	DSN	UK	None
		Presence of dedicated storage space for materials either within building or on site skips with good access for collections (2 m^2 per 1000 m^2 up to 10 m^2 max)	-	DSN	UK	None
		Major Building elements will be evaluated against the specifications set out in the Green Guide to Specification	-	DSN	UK	None
		Timber for key elements including structural timber, cladding, carcassing, internal joinery is specified to come from sustainably managed sources	-	DSN	UK	Yes
		Specifications of timber panel products use only timber that complies with above requirements. This elates specifically to plywood and other composite panel products and to composite timber doors	-	DSN	UK	Yes
		There is reuse of > 50% of existing facades	%	DSN	UK	None
		There is reuse of > 80% of major structure by building volume	%	DSN	UK	None
		There is use of crushed aggregate or masonry for use in structure, slabs, roads, etc	-	DSN	UK	None
		There is corporate policy endorsed at Board level and operational procedures for the collection and recycling of office consumables. Should cover paper, printer, cartridges, toner cartridges, plastics	-	O	UK	None
		There is information on presence of hazardous materials is available for staff and contractors	-	O	UK	None
	Land use	The site has been previously built on or used for industrial purposes within the last 50 years	-	DSN	UK	None
		Land is ‘contaminated’ and where adequate steps have been taken to contain or clean the site prior to construction. Evidence of survey and consultants report demonstrate targets to be achieved	-	DSN	UK	None
	Ecology	Land is defined as of low ecological value	-	DSN	UK	None
		Seeking and acting on advice from Wildlife Trusts (AWTC) or a member of IEA on enhancement	-	DSN	UK	None
		Contract specification ensures that all trees over 100 mm trunk dia, hedges, ponds, streams etc are maintained and adequately protected from damage during construction works	-	DSN	UK	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
BREEAM	Health & well-being	Refrigerant type has ODP of zero or no refrigerants	-	DSN	UK	None
		Presence of refrigerant leak detection system covering high risk parts of plant (coil can be omitted from this) or no refrigerants	-	DSN	UK	None
		Provision of automatic refrigerants pump down to coil or storage tanks with isolation valves or no refrigerants	-	DSN	UK	None
		Absence of Halon based fire fighting systems	-	DSN	UK	None
		Burners in boiler plant (except standby) have maximum NOx emission levels	mg/kWhr delivered heating energy	DSN	UK	None
		Site facilities reduce potential for run off to natural watercourses and/or municipal watercourses by 50% and where on site treatment such as oil interceptors / filtration is present	-	DSN	UK	None
		Specification of insulants avoids the use of ozone depleting substances in either manufacture or composition	-	DSN	UK	None
		There is an established and operational policy to operate maintenance schedules covering BOILER/BURNER systems including regular checking of controls, filters and cleaning in compliance with the HVCA Standard Maintenance Specification for Mechanical Services in Building. Use of an HVCA registered contractor would comply. Full maintenance records should be available	-	O	UK	None
CASBEE	IEQ	Background noise	dB	DSN	JPN	None
		Equipment noise	dB	DSN	JPN	None
		Sound insulation of openings	dB	DSN	JPN	None
		Sound insulation of partition walls	dB	DSN	JPN	None
		Sound insulation of floor slabs	dB	DSN	JPN	None
		Sound absorption	-	DSN	JPN	None
		Room temperature setting	Deg.C	DSN	JPN	None
		Variable loads and following-up control	-	DSN	JPN	None
		Perimeter performance	-	DSN	JPN	None
		Zoned control	-	DSN	JPN	None
		Temperature and humidity control	-	DSN	JPN	None
		Consideration for overtime work and holidays	-	DSN	JPN	None
		Allowance for after-hours air conditioning	-	DSN	JPN	None
		Monitoring systems	-	DSN	JPN	None
		Humidity control	%	DSN	JPN	None
		Type of air conditioning	-	DSN	JPN	None
		Daylight factor	-	DSN	JPN	None
		Openings by orientation	-	DSN	JPN	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
CASBEE	IEQ	Daylight devices	-	DSN	JPN	None
		Glare from light fixtures	-	DSN	JPN	None
		Daylight control	-	DSN	JPN	None
		Illuminance	lx	DSN	JPN	None
		Uniformity ratio of illuminance	-	DSN	JPN	None
		Lighting controllability	-	DSN	JPN	None
		Chemical pollutants	-	DSN	JPN	None
		Mineral fibers	-	DSN	JPN	None
		Mites, mold etc.	-	DSN	JPN	None
		Legionella	-	DSN	JPN	None
		Ventilation rate	-	DSN	JPN	None
		Natural ventilation performance	-	DSN	JPN	None
		Consideration for outside air intake	-	DSN	JPN	None
		Air supply planning	-	DSN	JPN	None
		CO_2 monitoring	-	DSN	JPN	None
		Control of smoking	-	DSN	JPN	None
	Servicability	Provision of space and storage	-	DSN	JPN	None
		Adaptation of building structure and services to IT innovation	-	DSN	JPN	None
		Barrier-free planning	-	DSN	JPN	None
		Perceived spaciousness and access to view	-	DSN	JPN	None
		Space for refreshment	-	DSN	JPN	None
		Décor planning	-	DSN	JPN	None
		Earthquake resistance	-	DSN	JPN	None
		Seismic isolation and vibration damping systems	-	DSN	JPN	None
		Necessary refurbishment interval for exterior finishes	yrs	DSN	JPN	None
		Necessary renewal interval for main interior finishes	yrs	DSN	JPN	None
		Necessary renewal interval for plumbing and wiring materials	yrs	DSN	JPN	None
		Necessary renewal interval for major equipment and services	yrs	DSN	JPN	None
		Reliability of HVAC system	-	DSN	JPN	None
		Reliability of water supply & drainage	-	DSN	JPN	None
		Reliability of electrical equipment	-	DSN	JPN	None
		Reliability: support method of machines & ducts	-	DSN	JPN	None
		Reliability: communications and IT equipment	-	DSN	JPN	None
		Allowance for floor-to-floor height	m	DSN	JPN	None
		Adaptability of floor layout	wall length/area	DSN	JPN	None
		Floor load margin	N/m^2	DSN	JPN	None
		Ease of air conditioning duct renewal	-	DSN	JPN	None
		Ease of water supply and drain pipe renewal	-	DSN	JPN	None
		Ease of electrical wiring renewal	-	DSN	JPN	None
		Ease of communications cable renewal	-	DSN	JPN	None
		Ease of equipment renewal	-	DSN	JPN	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
CASBEE	IEQ	Provision of backup space	-	DSN	JPN	None
	Outdoor environment on site	Preservation & creation of biotope	-	DSN	JPN	None
		Townscape & landscape	-	DSN	JPN	None
		Local characteristics & outdoor amenity	-	DSN	JPN	None
	Energy	Building thermal load	-	P-DSN	JPN	None
		Direct use of natural energy	-	DSN&C	JPN	None
		Converted use of renewable energy	-	DSN&C	JPN	None
		Efficiency: HVAC system	%	P-DSN	JPN	None
		Efficiency: Ventilation system	%	P-DSN	JPN	None
		Efficiency: Lighting system	%	P-DSN	JPN	None
		Efficiency: Hot water supply system	%	P-DSN	JPN	None
		Efficiency: Elevators	%	P-DSN	JPN	None
		Efficiency: Equipments for improving energy efficiency	-	P-DSN	JPN	None
		Monitoring	-	P-DSN	JPN	None
		Operational management system	-	P-DSN	JPN	None
	Resources & materials	Water saving	-	P-DSN	JPN	None
		Rainwater use systems	-	P-DSN	JPN	None
		Graywater reuse systems	-	P-DSN	JPN	None
		Efficiency of structural skeleton material reuse	%	P-DSN	JPN	None
		Efficiency of non-structural material reuse	%	P-DSN	JPN	None
		Timber from sustainable forestry	-	P-DSN	JPN	Yes
		Materials with low health risks	-	P-DSN	JPN	None
		Reuse of existing building structure etc.	-	P-DSN	JPN	None
		Predicted volume of recyclable materials	-	P-DSN	JPN	None
		Use of CFCs and halons - fire retardant	-	P-DSN	JPN	None
		Use of CFCs and halons - insulation materials	-	P-DSN	JPN	None
		Use of CFCs and halons - refrigerants	-	P-DSN	JPN	None
	Off-site environment	air pollution	-	DSN&C	JPN	None
		Noise, vibration and odor	-	DSN&C	JPN	None
		Wind damaage & sunlight obstrction	-	DSN&C	JPN	None
		Light pollution	-	P-DSN	JPN	None
		Heat island effect	-	P-DSN	JPN	None
		Load on local infrastructure	-	P-DSN	JPN	None
ECOPROFILE	External environment	Release to air	-	LC	Norway	None
		Release to ground	-	LC	Norway	None
		Release to water	-	LC	Norway	None
		Waste management	-	LC	Norway	None
		Outside areas	-	LC	Norway	None
		Transport	-	LC	Norway	None
	Resources	Energy	-	LC	Norway	None
		Water	-	LC	Norway	None
		Materials	-	LC	Norway	None
		Lnad	-	LC	Norway	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
ECOPROFILE	Indoor climate	Thermal climate	-	O&M	Norway	None
		Atmospheric climate	-	O&M	Norway	None
		Acoustic climate	-	O&M	Norway	None
		Actinic Climate	-	O&M	Norway	None
		Mechanical Climate	-	O&M	Norway	None
		Cross Factors	-	O&M	Norway	None
ECOQUANTUM		Resource depletion	-	LC	Netherlands	None
		Environmental emission	-	LC	Netherlands	None
		Energy	-	LC	Netherlands	None
		Waste	-	LC	Netherlands	None
ENVEST		Climate change	Eco-pts	DSN	UK	None
		Acid deposition	Eco-pts	DSN	UK	None
		Ozone Depletion	Eco-pts	DSN	UK	None
		Pollution to air: human toxicity	Eco-pts	DSN	UK	None
		Pollution to air: low level ozone creation	Eco-pts	DSN	UK	None
		Pollution to water: ecotoxicity	Eco-pts	DSN	UK	None
		Pollution to water: eutrophication	Eco-pts	DSN	UK	None
		Pollution to water: human toxicity	Eco-pts	DSN	UK	None
		Minerals extraction	Eco-pts	DSN	UK	None
		Water extraction	Eco-pts	DSN	UK	None
		Waste disposal	Eco-pts	DSN	UK	None
		Fossil fuel depletion and extraction	Eco-pts	DSN	UK	None
EQUER	Impact	Energy	GJ	LC	France	None
		Water	m^3	LC	France	None
		Acidification	kg SO_2	LC	France	None
		Smog	kg C_2H_2	LC	France	None
		Eutrophication	kg PO_4	LC	France	None
		Global warming	t CO_2 eq	LC	France	None
		Radioactive waste	dm^3	LC	France	None
		Other waste	tons	LC	France	None
GBTool	Site selection & development	Use of ecologically valuable or sensitive land	-	P-DSN	Canada, all	None
		Use of land with agricultural value	-	P-DSN	Canada, all	None
		Use of land vulnerable to flooding	m	P-DSN	Canada, all	None
		Use of land close to water	m	P-DSN	Canada, all	None
		Use of brownfield lands or contaminated land	-	P-DSN	Canada, all	None
		Proximity of site to public transportation	m	P-DSN	Canada, all	None
		Proximity to centres of employment from Residential occupancies	m	P-DSN	Canada, all	None
		Proximity to commercial and cultural facilities	m	P-DSN	Canada, all	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
GBTool	Site selection & development	Proximity to public green space	m	P-DSN	Canada, all	None
		Assessment of renewables feasibility	-	P-DSN	Canada, all	None
		Development density	%	DSN	Canada, all	None
		Mixed uses within the project	-	DSN	Canada, all	None
		Relationship of design with existing streetscapes	-	DSN	Canada, all	None
		Maintenance of heritage value	-	DSN	Canada, all	None
		Support for bicycle use	No.	DSN	Canada, all	None
		Use of private vehicles	%	DSN	Canada, all	None
		Use of native plantings	% area	DSN&C	Canada, all	None
		Use of trees for solar shading and sequestration of carbon dioxide	% frontage	DSN&C	Canada, all	None
		Maintenance or development of wildlife corridors	m (width)	DSN&C	Canada, all	None
	Energy & resource consumption	Primary energy embodied in construction materials	GJ/m^2	DSN	Canada, all	None
		Primary non-renewable energy used for building operations	$MJ/m^2/yr$	O	Canada, all	None
		Electrical peak demand for building operations	W/m^2	O	Canada, all	None
		Use of off-site energy that is generated from renewable sources	%	DSN	Canada, all	None
		Use of on-site renewable energy systems	$MJ/m^2/yr$	DSN	Canada, all	None
		Commissioning of building systems	-	DSN&C	Canada, all	None
		Re-use of existing structures	% of area	DSN	Canada, all	None
		Re-use of salvaged materials	% by cost	DSN	Canada, all	None
		Use of recycled materials from off-site sources	% by area	DSN	Canada, all	None
		Use of bio-based products obtained from sustainable sources	% by cost	DSN	Canada, all	Yes
		Use of materials that are locally produced	% by weight	DSN	Canada, all	None
		Design for disassembly, re-use or recycling	-	DSN	Canada, all	None
		Water embodied in materials	L/kg	DSN	Canada, all	None
		Use of potable water for site irrigation	m^3/m^2	DSN	Canada, all	None
		Use of potable water for building systems and occupant needs	L/p/d	DSN	Canada, all	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
GBTool	Site selection & development	GHG emissions embodied in construction materials	GJ/m^2	DSN	Canada, all	None
		GHG emissions from all energy used for annual building operations	kg CO_2 eq./m^2/yr	O	Canada, all	None
		Emission of ozone-depleting substances from building operations	g/m^2/yr	O	Canada, all	None
		Emission of acidifying emissions from building operations	kg/m^2/yr	O	Canada, all	None
		Emissions leading to photo-oxidants from building operations	g/m^2/yr	O	Canada, all	None
		Solid waste resulting from construction and demolition process	%	CONS	Canada, all	None
		Solid waste resulting from building operations	%	DSN	Canada, all	None
		Embodied waste water	L/kg	DSN	Canada, all	None
		Liquid effluents from building operations sent off the site	L/p/d	DSN	Canada, all	None
		Retention of rainwater for later re-use	L/m^2	DSN	Canada, all	None
		Minimization of untreated stormwater sent off the site	%	DSN	Canada, all	None
		Disturbance of water courses or other natural features of the site	-	DSN&C	Canada, all	None
		Impact of construction process or landscaping on soil erosion	-	DSN&C	Canada, all	None
		Adverse wind conditions at grade around tall buildings	-	DSN	Canada, all	None
		Hazardous waste on site	-	O	Canada, all	None
		Impact of building on access to daylight or solar energy potential of adjacent property	%	DSN	Canada, all	None
		Cumulative thermal changes to lake water or sub-surface aquifers	Deg.C	DSN	Canada, all	None
		Heat Island Effect - landscaping and paved areas	%	DSN	Canada, all	None
		Heat Island Effect - roofing	%	DSN	Canada, all	None
		Atmospheric light pollution	%	DSN	Canada, all	None
		Mercury waste from power generation	-	DSN	Canada, all	None
		Nuclear waste from power generation	-	DSN	Canada, all	None

P-DSN: Pre-design, DSN: Design, DSN&C: Design & Construction, CONS: Construction, O: Operation, O&M: Operation & maintenance, LC: Life cycle

Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
GBTool	Indoor environmental quality	Protection of materials during construction phase	-	CONS	Canada, all	None
		Removal, before occupancy, of pollutants emitted by new interior finish materials	-	CONS	Canada, all	None
		Selection of interior finish materials with minimal off-gassing of pollutants	-	DSN	Canada, all	None
		Pollutant migration between occupancies	-	DSN	Canada, all	None
		Pollutants generated by building maintenance	-	O	Canada, all	None
		Pollutants generated by occupant activities	-	O	Canada, all	None
		Limitation of CO_2 concentrations	ppm	DSN	Canada, all	None
		IAQ monitoring during building operations	-	DSN	Canada, all	None
		Ventilation in naturally ventilated occupancies	-	DSN	Canada, all	None
		Ventilation in mechanically ventilated occupancies	-	DSN	Canada, all	None
		Air movement in mechanically ventilated occupancies	m/s	DSN	Canada, all	None
		Ventilation effectiveness in mechanically ventilated occupancies	Eac (Air change effective ness)	DSN	Canada, all	None
		Air temperature and relative humidity in mechanically ventilated occupancies	m^2	DSN	Canada, all	None
		Air temperature in naturally ventilated occupancies	Deg.C	DSN	Canada, all	None
		Daylighting in primary occupancy areas	DF (Daylight Factor)	DSN	Canada, all	None
		Glare in non-residential occupancies	-	DSN	Canada, all	None
		Area of lighting control system zones in non-residential occupancies	m^2	DSN	Canada, all	None
		Lighting systems in non-residential occupancies	-	DSN	Canada, all	None
		Noise attenuation through the exterior fenestration	STC	DSN	Canada, all	None
		Transmission of building equipment noise to primary occupancies	NC	DSN	Canada, all	None
		Noise attenuation between primary occupancy areas	STC	DSN	Canada, all	None
		Acoustic performance within primary occupancy areas	-	DSN	Canada, all	None
		Electro-Magnetic Pollution	-	DSN	Canada, all	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
GBTool	Functionality & controllability	Efficiency of space utilization	%	DSN	Canada, all	None
		Maintenance of core functions during power outages	days	DSN	Canada, all	None
		Provision of building management control system	-	DSN	Canada, all	None
		Capability for partial operation of building technical systems	-	DSN	Canada, all	None
		Controllability of systems by occupants	-	DSN	Canada, all	None
	Long term performance	Maintenance of building envelope performance	-	DSN	Canada, all	None
		Ability to modify technical building systems	-	DSN	Canada, all	None
		Constraints imposed by structure	Load Kn/m^2	DSN	Canada, all	None
		Constraints imposed by floor-to-floor heights	m (height)	DSN	Canada, all	None
		Constraints imposed by building envelope and technical systems	-	DSN	Canada, all	None
		Adaptability to future changes in type of energy supply	-	DSN	Canada, all	None
		Measures taken for on-going monitoring and verification of performance	-	DSN	Canada, all	None
		Provision of as-built drawings and documentation	-	DSN	Canada, all	None
		Provision and maintenance of a building log	-	O	Canada, all	None
		Performance incentives in leases or sales agreements	-	O	Canada, all	None
		Training of operating staff	-	O	Canada, all	None
	Social & economic aspects	Life-cycle cost	$\$/m^2$	DSN&C	Canada, all	None
		Construction cost	$\$/m^2$	DSN&C	Canada, all	None
		Operating and maintenance cost	$\$/m^2$	DSN	Canada, all	None
		Affordability of rental or cost levels	%	DSN	Canada, all	None
		Support of Local Economy	%	DSN&C	Canada, all	None
		Externality costs	$\$/m^2$	DSN&C	Canada, all	None
		Security for building users	-	DSN	Canada, all	None
		Access for physically handicapped persons	%	DSN	Canada, all	None
		Access to direct sunlight from principal day-time living areas of dwelling units	%	DSN	Canada, all	None

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Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
GBTool	Social & economic aspects	Access to private open space from dwelling units	%	DSN	Canada, all	None
		Visual privacy from the exterior in principal areas of dwelling units	%	DSN	Canada, all	None
		Access to views from work areas	m	DSN	Canada, all	None
Green Globes	Energy & Resource	Energy consumption	MJ/m²/yr	O	Canada	None
		Energy features	-	O	Canada	None
		Energy management	-	O	Canada	None
		Transportation	m	O	Canada	None
	Water consumption	Water efficiency	-	O	Canada	None
		Water use target	m³/m²/yr	O	Canada	None
	Resources	Waste reduction & recycling	-	DSN	Canada	None
		Site (ecology)	-	DSN	Canada	None
	Environmental management	EMS documentation	-	DSN	Canada	None
		Purchasing policy	-	DSN	Canada	None
		Emergency response	-	DSN	Canada	None
		Tenant awareness	-	DSN	Canada	None
	Indoor environment	Indoor air	-	DSN	Canada	None
		Lighting	-	DSN	Canada	None
		Noise	-	DSN	Canada	None
	Emissions	Air emissions	-	DSN	Canada	None
		Ozone depletion	-	DSN	Canada	None
		Water effluents	-	DSN	Canada	None
		Hazardous materials	-	DSN	Canada	None
		Hazardous products, health & safety and WHMIS	-	DSN	Canada	None
GreenCalc		Materials	-	LC	Netherland	None
		Energy	-	LC	Netherland	None
		Water	-	LC	Netherland	None
		Mobility	-	LC	Netherland	None
LEED	Sustainable sites	Erosion & Sedimentation Control	-	DSN	USA	None
		Site Selection	-	DSN	USA	None
		Urban Redevelopment	-	DSN	USA	None
		Brownfield Redevelopment	-	DSN	USA	None
		Alternative Transportation	-	DSN	USA	None
		Reduced Site Disturbance	-	DSN	USA	None
		Stormwater Management	-	DSN	USA	None
		Landscape & Exterior Design to Reduce Heat Islands	-	DSN	USA	None
		Light Pollution Reduction	-	DSN	USA	None

P-DSN: Pre-design, DSN: Design, DSN&C: Design & Construction, CONS: Construction, O: Operation, O&M: Operation & maintenance, LC: Life cycle

Tools	Issue	Indicator	Unit	Phase	Country	Relev. Timber
LEED	Water efficiency	Water Efficient Landscaping	%	O	USA	None
		Innovative Wastewater Technologies	-	DSN	USA	None
		Water Use Reduction	%	O	USA	None
	Energy & atmosphere	Fundamental Building Systems Commissioning	-	DSN	USA	None
		Minimum Energy Performance	-	DSN	USA	None
		CFC Reduction in HVAC&R Equipment	-	DSN	USA	None
		Optimize Energy Performance	%	DSN	USA	None
		Renewable Energy	%	DSN	USA	None
		Additional Commissioning	-	DSN	USA	None
		Ozone Depletion	-	DSN	USA	None
		Measurement & Verification	-	DSN	USA	None
		Green Power	-	DSN	USA	None
	Materials & resources	Storage & Collection of Recyclables	-	DSN	USA	None
		Building Reuse	%	DSN	USA	None
		Construction Waste Management	%	DSN	USA	None
		Resource Reuse	%	DSN	USA	None
		Recycled Content	%	DSN	USA	None
		Local/Regional Materials	%	DSN	USA	None
		Rapidly Renewable Materials	-	DSN	USA	None
		Certified Wood	-	DSN	USA	Yes
	Indoor environmental quality	Minimum IAQ Performance	-	DSN	USA	None
		Environmental Tobacco Smoke (ETS) Control	-	DSN	USA	None
		Carbon Dioxide (CO_2) Monitoring	-	DSN	USA	None
		Increase Ventilation Effectiveness	-	DSN	USA	None
		Construction IAQ Management Plan	-	DSN	USA	None
		Low-Emitting Materials	-	DSN	USA	None
		Indoor Chemical & Pollutant Source Control	-	DSN	USA	None
		Controllability of Systems	-	DSN	USA	None
		Controllability of Systems	-	DSN	USA	None
		Thermal Comfort	-	O	USA	None
		Daylight & Views	%	O	USA	None
	Innovation & design process	Innovation in Design	-	DSN	USA	None
		LEED™ Accredited Professional	-	DSN	USA	None

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Appendix C - Indicators for wood in existing tools

Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Resource depletion & efficiency	Abundant material	-	Loading	MNF	EcoSpecifier (R)	Australia	Wood is abundant in Australia and easy to recycle and reuse (IND)
	Reuse potential	-	Loading	MNF	EcoSpecifier (R)	Australia	// (IND)
	Least processed materials	-	Loading	MNF	EcoSpecifier (R)	Australia	// (IND)
Materials	Reuse of façade	%	Resource & Material	DSN	Green Star (R)	Australia	Timber is used for façade and structure (old building) (IND)
	Reuse of structure	%	Resource & Material	DSN	Green Star (R)	Australia	// (IND)
	Sustainable timber	%	Resource & Material	DSN	Green Star (R)	Australia	(DR)
	Reuse of existing buildings	-	Resource & Material	DSN	Green Globes (R)	Canada	(IND)
	Reuse and recycling of demolition waste	-	Resource & Material	DSN	Green Globes (R)	Canada	(IND)
	Future facilities for recycling	-	Resource & Material	DSN	Green Globes (R)	Canada	(IND)
Materials & resources	There is no asbestos in structure, services, lifts, etc, or where asbestos survey has been carried out and all asbestos either removed or contained and identified within H&S plan	-	Resource & materials	DSN	BREEAM (R)	UK	e.g. CCA treated timber (IND)
	Timber for key elements including structural timber, cladding, carcassing, internal joinery is specified to come from sustainably managed sources	-	Resource & materials	DSN	BREEAM (R)	UK	(DR)

Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Materials & resources	Specifications of wood panel products use only wood that complies with above requirements. This elates specifically to plywood and other composite panel products and to composite wood doors	-	Resource & materials	DSN	BREEAM (R)	UK	(DR)
	There is reuse of > 50% of existing facades	%	Resource & materials	DSN	BREEAM (R)	UK	Wood has high reusability (IND)
	There is reuse of > 80% of major structure by building volume	%	Resource & materials	DSN	BREEAM (R)	UK	Wood has high reusability (IND)
	Building Reuse	%	Resource & materials	DSN	LEED (R)	USA	// (IND)
	Resource Reuse	%	Resource & materials	DSN	LEED (R)	USA	// (IND)
	Recycled Content	%	Resource & materials	DSN	LEED (R)	USA	// (IND)
	Certified Wood	-	Resource & materials	DSN	LEED (R)	USA	(DR)
	Timber from sustainable forestry	-	Resource & materials	P-DSN	CASBEE (R)	Japan	(DR)
	Reuse of existing building structure etc.	-	Resource & materials	P-Dsn	CASBEE (R)	Japan	Wood has high reusability (IND)
	Materials used for initial project construction	% weight	Resource & Material	CNST	EPGB (R)	Australia	Wood formwork, temporary wall etc. (IND)
	Materials likely to be recoverable in future	% weight	Resource & Material	CNST	EPGB (R)	Australia	Wood can be highly Recyclable (IND)
	Renewable resources	% by weight	Resource & Material	CNST	EPGB (R)	Australia	// (IND)

Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Energy & resource consumption	Primary energy embodied in construction materials	GJ/m^2	Resource & materials	DSN	GBTool (R)	Canada	Timber is also major construction material (IND)
	Re-use of existing structures	% of area	Resource & materials	DSN	GBTool (R)	Canada	// (IND)
	Re-use of salvaged materials	% by cost	Resource & materials	DSN	GBTool (R)	Canada	// (IND)
	Use of recycled materials from off-site sources	% by area	Resource & materials	DSN	GBTool (R)	Canada	// (IND)
	Use of bio-based products obtained from sustainable sources	% by cost	Resource & materials	DSN	GBTool (R)	Canada	// (IND)
	Use of materials that are locally produced	% by weight	Resource & materials	DSN	GBTool (R)	Canada	// (IND)
Air quality	Moisture control	-	IEQ	DSN	EPGB (R)	Australia	Wood product can absorb moisture (IND)
	Ventilation and fresh air delivery	-	IEQ	DSN	EPGB (R)	Australia	Timber construction has more openings for air circulation (IND)
Noise	Noise attenuation through the building envelope	-	IEQ	DSN	EPGB (R)	Australia	Timber structures may be not good prevention of noise from out/inside (IND).
	Noise attenuation between occupant units	-	IEQ	DSN	EPGB (R)	Australia	// (IND)
	Noise, vibration and odor	-	IEQ	DSN	CASBEE (R)	Japan	// (IND)
Thermal comfort	Air temperature	-	IEQ	DSN	EPGB (R)	Australia	temperature and humidity are related to ventilation (IND)
	Relative humidity	-	IEQ	DSN	EPGB (R)	Australia	// (IND)
	Primary ground floor construction type and area	m^2	IEQ	DSN	BASIX (R)	Australia	Timber can be used for ground floor construction (IND)
	Secondary ground floor construction type and area	m^2	IEQ	DSN	BASIX (R)	Australia	// (IND)
	Primary external wall type and area	m^2	IEQ	DSN	BASIX (R)	Australia	e.g., Autoclaved aerated concrete/double brick/ brick veneer/timber weatherboard or cement sheet (IND)
	Secondary external wall type and area	m^2	IEQ	DSN	BASIX (R)	Australia	Timber can be used for wall (IND)
	Wall shared with adjoining dwelling type and area	m^2	IEQ	DSN	BASIX (R)	Australia	// (IND)

Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Thermal comfort	Air temperature	m^2	IEQ	DSN	BASIX (R)	Australia	Timber can be used for wall (IND)
	Ceiling and roof type and area	m^2	IEQ	DSN	BASIX (R)	Australia	It can be used for ceiling and roof (IND)
	Glazing frame type	-	IEQ	DSN	BASIX (R)	Australia	Autoclaved aerated concrete/double brick/brick veneer/timber weatherboard or cement sheet (IND)
	Floor insulation	-	IEQ	DSN	BASIX (R)	Australia	It can be used for floor insulation (IND)
	External wall insulation	-	IEQ	DSN	BASIX (R)	Australia	It can be used for wall (IND)
	Ceiling and roof insulation	-	IEQ	DSN	BASIX (R)	Australia	It can be used for ceiling and roof (IND)
	Roof ventilation	-	IEQ	DSN	BASIX (R)	Australia	// (IND)
	Temperature and humidity control	-	IEQ	DSN	CASBEE (R)	Japan	Related to ventilation (IND)
	Humidity control	%	IEQ	DSN	CASBEE (R)	Japan	// (IND)
IAQ	Indoor air	-	IEQ	DSN	Green Globes (R)	Canada	(IND)
	Noise	-	IEQ	DSN	Green Globes (R)	Canada	(IND)
	Formaldehyde	ppm	IEQ	O & M	NABERS (R)	Australia	e.g. Particle board has formaldehyde (IND)
	Ventilation rates	-	IEQ	O & M	Green Star (R)	Australia	Timber construction has more openings for air circulation (IND)
	Thermal modeling	-	IEQ	O & M	Green Star (R)	Australia	This is related to heat and ventilation
	Air change effectiveness	%	IEQ	O & M	Green Star (R)	Australia	Timber construction has more openings for air circulation (IND)
	Noise attenuation through the exterior fenestration	STC	IEQ	O & M	GBTool (R)	Canada, all	Timber structures may be not good prevention of noise from out/inside (IND)
	Transmission of building equipment noise to primary occupancies	NC	IEQ	O & M	GBTool (R)	Canada, all	// (IND)
	Noise attenuation between primary occupancy areas	STC	IEQ	O & M	GBTool (R)	Canada, all	// (IND)
	Acoustic performance within primary occupancy areas	-	IEQ	O & M	GBTool (R)	Canada, all	Timber structures may be not good prevention of noise from out/inside (IND)
	Indoor air quality	g Total VOC	IEQ	LC	BEES (A)	USA	(IND)

Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Energy	Thermal performance	MJ/m²*year	Resource & Material	OPR	NatHERS (R)	Australia	Timber cladding framing and flooring (IND)
	Thermal performance	MJ/m²*year	Resource & Material	OPR	AccuRate (R)	Australia	// (IND)
	Thermal performance	MJ/m²*year	Resource & Material	OPR	BERS (R)	Australia	// (IND)
	Thermal performance	MJ/m²*year	Resource & Material	OPR	Firstrate (R)	Australia	// (IND)
Occupant satisfaction	Overall temperature satisfaction	-	-	O & M	NABERS (R)	Australia	Heat conductivity and insulation different depending on the materials and construction (IND)
	How cold it gets	-	-	O & M	NABERS (R)	Australia	// (IND)
	How hot it gets	-	-	O & M	NABERS (R)	Australia	// (IND)
	Overall ventilation satisfaction	-	-	O & M	NABERS (R)	Australia	Openings for air circulation (IND)
	Air freshness	-	-	O & M	NABERS (R)	Australia	// (IND)
	Air movement	-	-	O & M	NABERS (R)	Australia	// (IND)
Long term performance	Maintenance of building envelope performance	-	Management	DSN & OPR	GBTool (R)	Canada, all	For timber, people doesn't like timber envelope due to the need of frequent maintenance in some circumstance (IND)
Maintenance of performance	Access to building elements for maintenance and replacement	-	Functionality	O & M	EPGB (R)	Australia	For easiness for application of maintenance (IND)
	Selection of material durability appropriate to planned service life	-	Functionality	O & M	EPGB (R)	Australia	(IND)
	Protection of materials from destructive elements	-	Functionality	O & M	EPGB (R)	Australia	Timber house can be attacked by termite (IND)
	Ability to maintain performance under abnormal conditions	-	Functionality	O & M	EPGB (R)	Australia	Ability to remain serviceable after abnormal condition (IND)
	Maintenance of building envelope performance	-	Functionality	D&O	GBTool (R)	Canada, all	(IND)

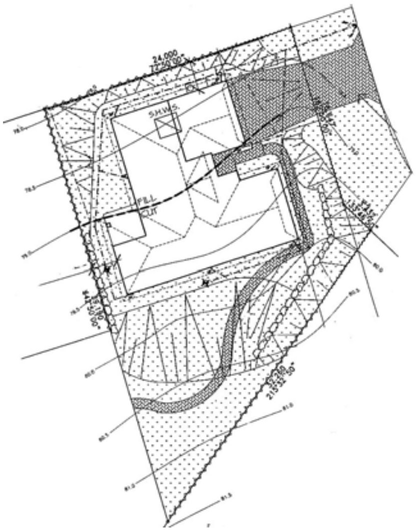
Issue	Indicator	Unit	Group	Phase	Tool (R/A)	Country	Note (relevance to wood)
Risk Toxic material	Sick Building Syndrome (SBS)	-	Material hazard	DSN	EPGB	Australia	e.g., Leaky building syndrome which found in Canada and New Zealand (IND).
	Air emissions	-	Loading	DSN	Green Globes	Canada	(IND)
	Toxic material presence	-	Loading	O & M	NABERS	Australia	CCA-treated timber though not proven to be directly harmful for humans has raised concerns of the public the extent of its toxicity (IND)
	Reduced life cycle toxicity	-	Loading	O & M	Ecospecifier		(IND)
	Human health	g C2H2 eq.	Human health	LC	BEES	USA	(IND)
Solid wastes	Construction process wastes	% tonnes	Loading	CNST	EPGB	Australia	Wood is generated as construction waste in residential building) 5% basically wasted (IND)
Others	Documented manufacturer claim	-	-	-	Ecospecifier	Australia	Some wood uses need certificate from manufacturer (IND)
	Australian standard	-	-	-	Ecospecifier	Australia	(IND)

MNF (Manufacturing), DSN (Design), P-DSN (Post design), CNST (Construction), OPR (Operation), DSN & OPR (Design and operation), O & M (Operation and management) and LC (Life cycle)
(DR): Direct, (IND): Indirect

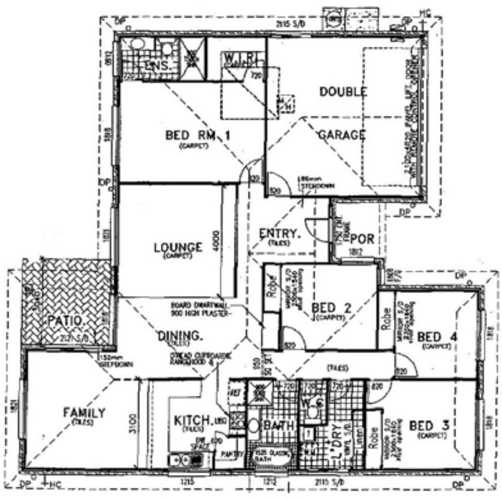
Appendix D - Information on example house for case study

In the testing tools, the example house was selected from Queensland, because QLD is Australia's fastest growing state.

House plans



Site plan of the example house



Floor plan of the example house

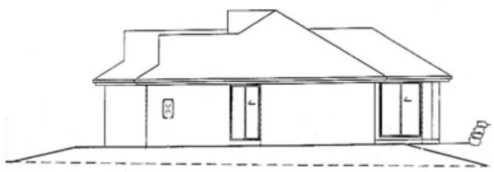
Elevation

East

West

South

North



Elevation

Information for example house

Information	Amount	Note
Frame & Wall type	-	Timber Frame Brick Veneer Wall
Total area (sq. metre)	725	Single storey brick veneer on slab, tiled roof (25° pitch).
Total floor area (sq. metre)	194	4 bedrooms, 2 pedestal
Impervious surfaces (sq. metre)	30	Drive way
Semi-pervious surfaces (sq. metre)	10	-
Pervious surfaces (sq. metre)	435	Garden (200 sq. m assumed 30% native), Lawn (235 sq. m)
Occupancy (person)	4	2 adults and 2children
Average hours per week occupied (hours)	102	Weekday: 17/d X 5=75 hours, Weekend: (17X1)+(10X1)=27 hours, 75+27=102 hours
Energy consumption (electricity, kWh/yr)*	11372	Most households consume only electricity (89%) and gas (11%). Energy consumption is assumed as 20GJ/person/yr*
Energy consumption (gas, MJ/yr)*	5060	
Water consumption (cubic metre/yr)	200	340L/d/p (900 L/d/household, see reference) But, assumed 200 m^3 (because we considered peak load gap)
Waste generation (kg/yr)*	905	Assumed based on ABS (1998) 10% recycled and rest send to landfill

Residential energy consumption

For energy consumption, the use in QLD is quite different with the amount used for heating and cooling being significantly lower. Thus, Australian residential energy consumption data is used in this example. Then, the consumption data is allocated into consumption rate (%) for QLD energy use.

Residential energy consumption

Year	Per Person (GJ)	Total (PJ)
1973-74	16.9	231.3
1993-94	19.6	349.3
2009-10(a)	21.6	459.7

(a) Projected.
Gigajoule (GJ): one thousand million joules of energy.
Petajoule (PJ): one thousand million million joules of energy.
ABS (1998) Australian Social Trends 1997 Housing - Housing & Lifestyle: Environment & the home

Queensland household energy use

Use	%	Energy source
Water heating	38%	Electricity
Refrigeration	18%	Electricity
Cooking	11%	Gas
Lighting	11%	Electricity
Heating/cooling	5%	Electricity
Other	17%	Electricity

Source: Queensland Conservation Council, 2004

Energy consumption for Case study

	20GJ/p/yr	2 adults	2 kids	Sum GJ)	Unit (GJ -> MJ)	Electricity (3.6 MJ/kWh)
Electricity	89.0%	35.60	5.34	40.94	40940	11372.2
Natural gas	11.0%	4.40	0.66	5.06	5060	5060.0
Total	100.0%	40.00	6.00	46.00	46000	

Domestic waste stream

Material type	Includes	Annual waste Generation/house per hold (kg)
Organic compostable	Garden, food/kitchen, other compostables.	456
Paper	Newspaper, writing paper, packaging, cardboard, milk cartons etc.	233
Plastics	PET, HDPE, LDPE, plastic bags, polypropylene, polystyrene, etc.	64.1
Glass	Jars, bottles, plateglass etc.	61.1
Ferrous metal	Steel cans, white goods, packaging etc.	28.3
Other materials	Ceramics (bricks, tiles etc), dust, dirt, rock, soil, ash, etc.	26.1
Other organic	Textiles, wood, leather, rubber, oils.	24.3
Non-ferrous	Aluminium packaging and cans, copper, brass, etc.	8
Household hazardous	Paint, dry cell batteries, car batteries, fluorescent globes, etc.	4.9
Sum		905.8

ABS (1998): http://www.abs.gov.au/Ausstats/abs@.nsf/0/c688b2a3026f1338ca2569ad000402d8?OpenDocument

Appendix E - NABERS Data Sheet

General Input data for Example House (EH) and Alternatives (AH)

Show instructions

Show technical background

NABERS Residential

General Inputs

General data required	Units	Input value
Number of occupants	*people*	4
Hours per week	*number*	102
Number of weeks per year the home is occupied	*number*	48
Rated floor area	*m^2*	194
Post Code		4300
Total area of site	*m^2*	725

Energy and Greenhouse data for Example House (EH) and Alternatives (AH)

Show instructions

Show technical background

NABERS Residential

Energy & Greenhouse

Fuel type	*Units*	Quantity	kg of CO_2e/year
Electricity	*kWh/ year*	11372	11599
Gas	*MJ/year*	5060	281
Coal black	*kg/year*		0
Coal brown	*kg/year*		0
Oil / diesel	*Litres/year*		0
Firewood	*tonnes/year*		0
		TOTAL	11881
		Normalised: kgCO_2e/person/year	3258
		SCORE	**2.3**

click "default" to reset values to default for region

Greenhouse coefficients

Fuel	value	*Units*
Electricity	1.02	*kgCO_2e/kWh*
Gas	0.20	*kgCO_2e/kWh*
Coal Black	0.32	*kgCO_2e/kWh*
Coal Brown	0.32	*kgCO_2e/kWh*
Oil / diesel	0.27	*kgCO_2e/kWh*
Firewood	1.80	*kgCO_2e/kg*

Transport data for Example House (EH) and Alternatives (AH)

Vehicle type	Engine size (litres)	Fuel Type	Calculated fuel consumption L/100km	Alternative fuel consumption L/100km	Yearly distance travelled (km)	Calculated greenhouse emissions kg/occupant/year
car	2	petrol	-	9.11	10000	590
4WD	4	petrol	-	12	15000	1166
Click "Add? to add a new row						
					Score	2.3

Water data for Example House (EH) and Alternatives (AH)

Show instructions

Show technical background

NABERS Residential Water Use

Water Consumption	*Units*	Quantity
Metered water consumption from all sources	*m^3 per year*	200
Normalised: m^3/person/year		50
	SCORE	4.2

Stormwater runoff data for Example House (EH) and Alternatives (AH)

Show instructions

Show technical background

NABERS Residential Stormwater Runoff

Select assessment method

- **Method 1** (selected)
- **Method 2**
- **Method 3**

Table 1:

Surface Type	*units*	
Impervious surfaces	*m^2 (in plan)*	30
Semi-pervious surfaces	*m^2 (in plan)*	10
Pervious surfaces	*m^2 (in plan)*	435
Other surface 1	*m^2 (in plan)*	0
Other surface 2	*m^2 (in plan)*	0

Table 2:

Value	*units*	
Metered stormwater reuse	*m^3/year*	
Annual rainfall	*mm/year*	
Evaporation	*m^3/year*	

Table 3:

Value	*units*	
Metered stormwater flows	*m^3/year*	

Calculated stormwater distortion index	0.8
SCORE Method 1	5.0

Stormwater pollution data for Example House (EH) and Alternatives (AH)

NABERS Residential

Show instructions | *Show technical background*

Stormwater Pollution

			Pollutant					Activities/use			
Area ID	**Surface Type**	**Area (m^2)**	**Loose organic matter**	**General rubbish**	**Toxic rubbish**	**Hydro-carbon spills**	**Sewage**	**Artificial fertiliser**	**Long residence herbicide**	**Pesticide**	**Car washing**
	Impervious	30	Nil	Minimal	Nil	Nil	Nil	≤1x per year	≤1x per year	≤1x per year	<1x per month
	Semi-pervious	10	Minimal	Minimal	Nil	Nil	Nil	≤1x per year	≤1x per year	≤1x per year	not applicable
	Pervious	435	Minimal	Nil	Nil	Nil	Nil	<4x per year	≤1x per year	≤1x per year	not applicable

Click "Add? to add a new row

Score 4.9

Sewage outfall volume data for Example House (EH) and Alternatives (AH)

NABERS Residential

Show instructions | *Show technical background*

Sewage Outfall Volume

Table 1: Method 1 - Direct Measurement

Item	***Units***	**volume**
Metered sewage outfall volume	*m^3/year*	

Table 2: Method 2 - Metered Estimation

Item	***Units***	**volume**
Metered fresh water	*m^3/year*	
Evaporation loss	*m^3/year*	
Irrigation	*m^3/year*	
Rainwater used internally	*m^3/year*	
Externally reticulated treated greywater	*m^3/year*	
Calculated sewage outfall	*m^3/year*	0

Table 3: Method 3 - Unmetered Estimation

Item	***Units***	**volume**
Lowest quarter metered fresh water	*m^3/quarter*	0.4
Calculated annual sewage outfall	*m^3/year*	1.6

Normalised sewage outfall volume	***m^3/occupant per year***	0.4
	SCORE	**5.0**

Landscape diversity data for Example House (EH) and Alternatives (AH)

NABERS Residential		Show instructions	
		Show technical background	
Landscape Diversity			
Area name	**Area (m^2)**	**% Native Cover**	**Complexity**
Garden	200	30%	2
Lawn	235	0%	1
Click "Add? to add a new row			
sum of areas	435	m^2	
total site area	725	m^2	
area as % of total	60%		
		Score	**1.3**

Toxic materials data for Example House (EH) and Alternatives (AH)

NABERS Residential						Show instructions			
						Show technical background			
Toxic Materials									
Toxic Material Category	Cleaning chemicals	Garden chemicals	Pool chemicals	Hydrocarbons	Paints varnishes and thinne	Batteries	Electronic Equipment	Smoke detectors	Fluorescent tubes
Use									
Present on site	☑	☑	☐	☑	☑	###	###	###	####
Presence score							1		
Storage									
Original container?	☑	☑	☐	☑	☑				
Container integrity?	☑	☑	☐	☑	☑				
No spills present?	☐	☑	☐	☐	☑				
Storage integrity?	☑	☑	☐	☑	☑				
Storage security?	☐	☐	☐	☐	☐				
Storage score							3.5		
Disposal									
Direct to environment					☐	☐	☐	☐	☐
To normal waste infrastructure or still on site					☑	☑	☑	☑	☑
Approved disposal method					☑	☑	☑	☑	☑
Disposal score							2.5		
Overall score							**2.3**		

Waste data for Example House (EH) and Alternatives (AH)

NABERS Residential		Show instructions / Show technical background
Waste		
General data required	***Units***	**waste quantity**
Weight of total waste	*kg*	905
Weight of waste sent to landfill	*kg*	635
	Total Waste Score	**3.0**
	Landfill Waste Score	**2.0**

Indoor Air Quality data for Example House (EH) and Alternatives (AH)

NABERS Residential	Show instructions / Show technical background
Indoor Air Quality	
Question	**tick for yes**
Are the floors, cupboards or other furniture made of particle board such as MDF, chipboard or other processed wood products?	☑
Is the garage connected to, or underneath, the house?	☑
Are there any unflued gas heaters in the house?	☐
Is a gas cooker used?	☑
Are there any open fireplaces?	☐
Are there any areas of the building that suffer from mould or damp?	☐
Are there any permanently fitted carpets in the house?	☑
Does anyone smoke within the house?	☐
Are there any cats, dogs or birds in the house (or any other furred or feathered pet)?	☐
Is the vacuum cleaner fitted with a HEPA filter?	☐
Has any paint or varnish been used inside the house within the past 2 years that was not specifically identified as being a nil VOC paint?	☐

Test results

Contaminant	**sampling period**	***unit***	**tick for yes**
TVOCs < 500µg/m³	*1 hour average*	*µg/m³*	☐
Any individual VOC <250µg/m³	*1 hour average*	*µg/m³*	☐
Respirable dust < 26mg/m□	*1 day average*	*mg/m□*	☐
Airbourne bacteria <1000CFU/m□	*as per equipment*	*CFU/m□*	☐
Airbourne fungi and mould <1000CFU/ m□	*as per equipment*	*CFU/m□*	☐
Dustmite <5000 mites per m□	*as per equipment*	*mites per m□*	☐
Unflued gas heater or stove			☐
Nitrogen dioxide	*1 hour average*	*ppm*	☐
Sulphur dioxide	*1 hour average*	*ppm*	☐
		Score	**1.6**

Occupant satisfaction data for Example House (EH) and Alternatives (AH)

NABERS Residential	*Show instructions* / *Show technical background*
Occupant Satisfaction	
	enter name
THERMAL	
Overall temperature satisfaction	3
How cold it gets	3
How hot it gets	3
Thermal Score	3.0
NOISE	
Overall noise satisfaction	3
Transfer of noise between rooms	3
Noise from air-conditioning, heating and lighting systems	2
Noise from outside the building	3
Noise Score	2.8
LIGHTING	
Overall lighting satisfaction	3
Level of natural light - general	3
Level of artificial light - general	3
Level of natural light - living areas	3
Level of artificial light - living areas	3
Level of natural light - kitchen	3
Level of artificial light - kitchen	3
Glare from light fittings	3
Glare from windows	3
Lighting Score	3.0
HEALTH	
Sore eyes	4
Headaches	4
Runny nose	4
Dry throat	4
Dry or irritated skin	4
Lethargy	4
Dizziness	4
Nausea	4
Health Score	4.0
TOTAL SCORE	3.4

Summary for Example House (EH) and Alternatives (AH)

NABERS Residential		*Show instructions* / *Show technical background*
Summary		
Environmental Issue	**Score**	
Energy/Greenhouse	2.3/5	..
Transport	2.3/5	..
Water Use	4.2/5	....
Stormwater Runoff	5.0/5	.....
Stormwater Pollution	4.9/5	....
Sewage Outfall	5.0/5	.....
Landscape Diversity	1.3/5	.
Toxic Materials	2.3/5	..
Waste Total	3.0/5	...
Waste Landfill	2.0/5	..
Indoor Air Quality	1.6/5	.
Occupant Satisfaction	3.4/5	...
Greenhouse Score	**2.3/5**	
Water Score	**4.7/5**	
Site Management Score	**2.7/5**	
Occupant Impact Score	**2.5/5**	
Overall Score	**4.0/10**	
Assessment	**Lower average**	

Appendix F - Description of Case Study Building for LISA

	Content		Unit	Default	Alternative1	Alternative2
Specification	Analysis period		Year	60	60	60
	Life expectancy of appliances		Year	10	10	10
	Life expectancy of building		Year	60	60	60
	Life expectancy of fit out		Year	10	10	10
	Occupant number		People	4	4	4
Construction	Doors/windows	Doors hollow	each	0	0	0
		Doors solid	each	10	10	10
		Windows		Single glazed, timber frame		
	Driveaway	Driveaway		Concrete		
		Driveaway area	m^2	40	40	40
	Fittings	Deck	-	Timber frame	Timber frame	**Steel frame**
		Stairs	-	Steel frame	**Timber frame**	Steel frame
	Garage / carport	Carport	-	None	None	None
		Garage	-	None	None	None
		Garage roof	-	None	None	None
	Insulation	Insulation	-	Fiber glass	Fiber glass	Fiber glass
	Internal finishes	Ceiling	-	Particleboard	**Timber**	**Plasterboard**
	Plumbing / elctrical services	Downpipes	-	Colorbond	Colorbond	Colorbond
		Guttering	-	Colorbond	Colorbond	Colorbond
	Roof	Roof cladding	-	Colorbond	Colorbond	Colorbond
		Roof structure	-	Timber frame	Timber frame	**Steel frame**
	Structure	Ground floor	-	Timber frame/boards, concrete peirs	Timber frame/boards, concrete peirs	**Steel frame, timber boards, concrete piers**
		Upper floor	-	Plywood	Plywood	Plywood
	Verandah	Verandah	-	Timber frame/boards	Timber frame/boards	Timber frame/boards
	Wall	Wall construction	-	Weatherboard clad, timber frame	Weatherboard clad, timber frame	**Weatherboard clad, steel frame**

Alternative 1: Timber based
Alternative 2: Steel based

	Content		Unit	Default	Alternative1	Alternative2
Appliances	Heating/cooling	Airconditioner (main)	-	3500W (1.5hp)	3500W (1.5hp)	3500W (1.5hp)
		Airconditioner (other)	-	2600W (1hp)	2600W (1hp)	2600W (1hp)
		Heater (main)	-	Reverse cycle 4700W	Reverse cycle 4700W	Reverse cycle 4700W
		Heater (other)	-	Bar heater 2400W	Bar heater 2400W	Bar heater 2400W
	Kitchen	Dishwasher	-	None	None	None
		Freezer	-	None	None	None
		Fridge/freezer	-	395 liter frost free	395 liter frost free	395 liter frost free
		Microwave oven	W	750	750	750
		Oven	-	Electric	Electric	Electric
		Stove/hotplates	-	Electric	Electric	Electric
	Laundry	Clothes dryer	kg	5	5	5
		Washing machine	-	6kg top load	6kg top load	6kg top load
	Other	Fans	fans	3	3	3
		TV	TVs	2	2	2
	Outside	Lawn mower	-	Petrol	Petrol	Petrol
		Whipper snipper	-	None	None	None
	Water heating	Water heater	-	Electric off-peak	Electric off-peak	Electric off-peak
Fit-out	Fittings	Cupboards		Timber	Timber	Timber
	Furniture	Beds	each	4	4	4
		Bedside drawers	-	None	None	None
		Coffee table	-	Timber	Timber	Timber
		Desk	-	Timber	Timber	Timber
		Dining setting	-	Timber	Timber	Timber
		Lounge setting	-	Timber	Timber	Timber
		TV unit	-	Timber	Timber	Timber
		Wardrobes	-	Timber	Timber	Timber
	Internal finishes	Carpet	-	Wool	Wool	Wool
		Foor tiles	-	Terracotta tiles	Terracotta tiles	Terracotta tiles
		Wall tiles	-	Ceramic tiles	Ceramic tiles	Ceramic tiles
	Plumbing/electric services	Electrical wiring	-	Copper	Copper	Copper
		Piping wastewater	-	PVC	PVC	PVC
		Piping water supply	-	Copper	Copper	Copper
	Swimming pool	Swimming pool	-	None	None	None

Alternative 1: Timber based
Alternative 2: Steel based

Appendix G - Glossary

Abiotic Resource Depletion (ARD)	Abiotic resource depletion is defined as extraction of minerals and fossil fuels due to inputs in the system (building product or building). To characterize the ARD impact, Abiotic Depletion Factor is used, which is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation.
Acidification Potential (AP)	Acidifying compounds reach ecosystems through dissolution in rain or wet deposition. This impact affects trees, soil, buildings, animals, and humans. This impact can be quantified using the 'Acidification Potentials (AP)' which is expressed as kg SO2 equivalents/ kg emission.
Acid rain	Rainwater that has an acidity content greater than the postulated natural pH of about 5.6. It is formed when sulfur dioxides and nitrogen oxides, as gases or fine particles in the atmosphere, combine with water vapor and precipitate as sulfuric acid or nitric acid in rain, snow, or fog. The dry forms are acidic gases or particulates. See acid deposition, sulfur dioxide, nitrogen oxides.
Air Change	The replacement of a quantity of air in a space within a given period of time, typically expressed air changes per hour. If a building has one air change per hour, this is equivalent to all of the air in the building being replaced in a one-hour period.
Biodiversity	The variety of all life forms-the different plants (flora), animals (fauna) and micro-organisms. It includes the genes they contain and the ecosystems they form. Biodiversity is often considered at three levels-genetic diversity, species diversity and ecosystem diversity.
Building Code	The local regulations that control design, construction, and materials used in construction. Building codes are usually based on health and safety standards.
Building envelope	Elements (walls, windows, roofs, skylights, etc.) and materials (insulation, vapor barriers, siding, etc.) that enclose a building. The building envelope is the thermal barrier between the indoor and outdoor environments and is a key factor in the sustainability of a building. Awell designed building envelope will minimize energy consumption for cooling and heating, and promote the influx of natural light.
Carcinogen	Cancer-causing agent, may be physical (e.g. radiation, asbestos fibers), viral, or chemical. Cancers arise from aberrations in cellular DNA.
Climate change	The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, climate change has been used synonymously with the term, global warming; scientists however, tend to use the term in the wider sense to also include natural changes in climate. See climate, global warming, greenhouse effect, enhanced greenhouse effect, radiative forcing.

Daylighting	The use of natural light to supplement or replace artificial lighting.
Ecotoxic	A substance that, if released into the environment, will cause or may cause immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.
Ecotoxicity	Ecosystem impact caused by toxic substances emissions which determines the Potentially Affected Fraction (PAF)** of species in relation to the concentration of toxic substances developed by RIVM for the Dutch Environmental Outlook.
Eutrophication Potential (EP)	Eutrophication is the addition of mineral nutrients to the soil or water. Eutrophication is based on the stoichiometric procedure of Heijungs *et al*. (1992), and expressed as kg PO4 equivalents/ kg emission.
Embodied energy	The energy consumed by all the processes associated with manufacturing products from the acquisition of natural resources to the delivery of the product.
Glazing	A covering of transport or translucent material (typically glass or plastic) used for admitting light. Glazing retards heat losses from radiation and convection.
Global warming potential (GWP)	The index used to translate the level of emissions of various gases into a common measure to compare their contributions to the absorption by the atmosphere of infrared radiation. GWPs are calculated as the absorption that would result from the emission of 1 kg of a gas to that from emission of 1 kg of carbon dioxide over 100 years.
Hazardous waste	Any waste that is considered toxic, corrosive, flammable, or otherwise dangerous and declared by regulations to be a hazardous waste.
Heating, Ventilating, and Air Conditioning System (HVAC)	A system that provides heating, ventilating, and/or cooling within or associated with a building.
Home Energy Rating System (HERS)	HERS measure and rate on a scale the relative energy efficiency of any house, regardless of age, efficiency, or fuel use. The rating is based on the efficiency of the thermal envelope and the heating, ventilating, ad air conditioning (HVAC) system and is obtained by on-site inspection and calculations. HERS calculations include estimates of annual energy performance and costs and recommendations for cost-effective energy-efficiency improvements.
Human Toxicity (HT)	Some toxic inventory items from the life cycle of building or building product can influent to human health. This is characterized into 'Human Toxicity Impact' using the characterisation factors, expressed as Human Toxicity Potentials (HTP). This is calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon.
Indoor Air Quality	Indoor environmental quality of a site. ASHRAE defines acceptable indoor air quality as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction.

Land use	Damage considered is the local effects of land occupation and land conversion, the regional effects of land occupation and land conversion. The local effect refers to the change in species numbers occurring on the occupied or converted land itself, and regional effect refers to the changes on the natural areas outside the occupied or converted area. Indicator is used Potentially Disappeared Fraction (PDF).
Life Cycle Cost (LCC)	Amount of money necessary to own, operate, and maintain a building over its useful life
Life Cycle Inventory (LCI)	List inputs to the systems in terms of raw materials and energy and outputs in terms of emissions to air and water and solid waste.
Life Cycle Impact Assessment (LCIA)	Environmental burdens identified in the LCI cause impacts on nature and society in many ways. These impacts are described and assessed in the Life Cycle Impact Assessment (LCIA). LCIA specifically uses impact categories and associated indicators to simply LCI results with regard to one or more environmental issues.
Mineral Impact (as damage in Ecoindicator 99)	Damage to Resources caused by extraction of minerals, When we quantify the quantity of resources, if we sum up only the known and easily exploitable deposits, the quantities are quite small in comparison to current yearly extractions. But if we include occurrences of very low concentrations or with very difficult access, the resource figures become huge. Thus, this method does not consider the quantity of resources as such, but rather the qualitative structure of resources.
Ozone Depletion Potential (ODP)	A thinning of ozone layer allows more harmful short wave radiation to reach the Earth's surface, potentially causing changes to ecosystems as flora and fauna have varying abilities to cope with it. There are also adverse effects on agricultural productivity. Effects on man can include increased skin cancer rates and eye cataracts, as well as suppression of the immune system. The characterisation model for quantifying the inventory items during the life cycle of building or building product is defined as ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission) which is developed by the World Meteorological Organisation (WMO).
Ozone depleting substance	A family of man-made compounds that includes, but are not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs. See ozone.
Ozone layer	A part of the earth's atmosphere that helps protect the planet's surface from the sun's potentially harmful ultraviolet radiation.
Photochemical Ozone Creation Potential (POCP)	Photochemical Ozone Creation Potential (POCP) for air emission of inventory items is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission.

Radiation	Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (ultra-violet, visible, and near infrared) while energy radiated from the Earth's surface and the atmosphere has a longer wavelength (e.g., infrared radiation) because the Earth is cooler than the Sun. See ultraviolet radiation, infrared radiation, solar radiation, longwave radiation, terrestrial radiation.
Respiratory organic	Respiratory effects on humans caused by organic substances
Respiratory inorganic	Respiratory effects on humans caused by inorganic substances, of PM10, PM2.5, TSP, NOx, NH3, CO, VOCs, and SOx.
Rating scheme	A procedure for calculating total annual energy consumption and costs of a building/building product and for signing a rating that establishes how the efficiency of a given building/building product compares to the efficiency of all other building/building products. Rating schemes use a scoring system to evaluate new and remodeled buildings against a selected standard for environmental performance. NABERS, Green Star etc in Australia and LEED in USA and BREEAM in UK evaluate environmental performance from a whole building perspective over a building's life cycle. NatHERS etc. scores buildings based on their energy efficiency, comfort and indoor environmental quality.
R-Value	A unit of thermal resistance used for comparing insulating values of different materials. The higher the R-Value of a material, the greater its insulating properties and the slower the heat flows through it.
Sick building syndrome	The Environmental Protection Agency and the National Institute of Occupational Safety and Health define Sick Building syndrome as "situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be spread throughout the building." Occupants experience relief of symptoms shortly after leaving the building.
Stakeholders	The broadest definition of 'stakeholder' brings in anyone who affects or is affected by a company's operations. The key new perception is that companies need to expand the range of interests considered in any new development from customers, shareholders, management and employees to such people as suppliers, local communities and pressure groups.
Star Rating Approach	Rating system in which stars are given to reflect energy efficiency of a house. For example, a rating of five stars on a scale of one to five stars represents the best rating possible.
Submetering	Breaking down the utility metering of a building to determine the proportionate energy use of specific building systems and appliances.

Sustainability	The concept of managing the use of natural resources so that the amount of the resource is not irretrievably depleted. The development of renewable alternatives to non-renewable resources is essential, and the stock of renewables in use must be maintained. Economic development taking place in this way is termed ‘Sustainable Development’ , and has been defined as ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs’.
Sustainable development	development that focuses on making social, economic and political progress to satisfy global human needs, desires, aspirations and potential without damaging the environment; also known as sustainable growth.
Thermal comfort	A combination of factors including temperature, humidity and air movement, which promotes maximum physiological well-being for humans.
Thermal Envelope	The building's exterior shell - walls, foundation, floors, ceiling, windows, doors, and roof
U-value	A measure of building element’s ability to conduct heat; the higher the U-value, the greater the conduction.
Ventilation	1) The process of replacing contaminated or stale air by fresh air. 2) The movement and circulation of outdoor air. 3) The volume of air entering or leaving the lungs in one respiratory cycle.
Ventilation rate	The volume of air passing through unit width of mixing layer per unit time
Volatile Organic Compound (VOC)	An organic compound that evaporates at room temperature and is often hazardous to human health, causing poor indoor air quality. Sources of VOCs include solvents and paints. Many materials commonly used in building construction (such as carpets, furniture, and paints) emit VOCs.

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