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A Practical Guide to Life Cycle Assessment of Buildings

Dominique Hes

Figure 1: House demolition

ABSTRACT

Life cycle assessment (LCA) is an internationally recognised and standardised (International Standards Organisation 1997) approach for assessing the environmental impacts of consumption and production. LCA is seen as the only method for evaluating and comparing alternatives, based on the environmental performance over the life of the alternative: that is, from material extraction through to use and disposal.

This note aims to provide an overview of how LCA is being applied in the building area, and to give practical guidance on using LCA and other life cycle approaches. It has been updated to include a discussion on the latest trends, data quality, data availability and tools for the built environment.

This note was originally published in November 2002 and titled GEN 51. Its authors were Tim Grant and Dominique Hes. It was based on the Greening the Building Life Cycle project of 2000–2001, funded by Environment Australia. The current note was revised and updated in May 2012 by Dominique Hes, with input from Tim Grant.

Introduction

Life cycle assessment measures and compares the environmental impacts of a common function or service.

LCA developed out of energy and resource profile analysis (Hunt and Franklin 1996) in the late 1960s and early 1970s, predominantly in the area of packaging. In the 1980s, environmental impacts beyond energy were added to the methodology including the greenhouse effect, ozone depletion, acid rain and eutrophication (nutrient loads in the environment). The concept of evaluating and comparing these impacts was developed through the 1980s and early 1990s, culminating in the development of a range of assessment methodologies in Northern Europe (Ahbe, Braunschweig et al 1990; Steen and Ryding 1991; Goedkoop 1995).

Differences Between LCA and LCC

There is often a misunderstanding of LCA and life cycle costing (LCC). In short, LCA is a method to account the environmental impacts of a material, product, structure or alternative over its life cycle, while LCC is the financial accounting that thing over its life. For example, the LCA impact of a floor covering 'x' over its life may be 50 tonnes of carbon dioxide leading to climate change impacts, 2000L of water use, and 500g of sulphur dioxide into the air, leading to acidification of water and soil bodies. LCC of the same flooring may be \$60/m^2 capital cost and \$120/ m^2 for maintenance and cleaning over the life of the floor. Key differences in the approaches are that environmental flows are not discounted over time (and may span 100 year timeframes or longer), however cost flows will normally be discounted into the future.

LCA measures a diverse group of impacts and may present results against a group of indicators, or weight those indicators into a single environmental indicator, while LCC deals with one common indicator – financial cost. Labour is generally not seen as an environmental impact in its own right, but will affect costs substantially.

Using LCA

The advice from the author to designers is to use LCA at critical decision points to analyse complex decisions and key innovations that could have unforeseen impacts.

Doing a comprehensive LCA for every building project would be neither cost nor time effective: it is better to rely on simplified guides based on life cycle thinking.

The four steps below (taken from ISO 14040, 1997) will help users with the LCA process.

1. Goal and scope definition

The goal of the study needs to be clearly identified, and will usually relate to a comparison of two or more alternatives, or the optimisation of a product system. The setting of the study scope includes decisions about what will be measured (system boundaries), what impacts will be used as a criteria for judgement, the level of data quality required, the data collection approach and a description of the product system and its alternatives.

The first stage is extremely important. The result of the LCA is heavily dependent on the decisions taken here. A preliminary LCA 'screening', (a quick dry run of the LCA with data from previous similar studies or existing software tools) is a useful step to help shape the goal-definition phase. After screening it is much easier to plan the rest of the project.

2. Inventory

The inventory stage collects environmental flow data relating to the production systems identified in the scope, and involves modelling this data to compute the overall emissions and resource uses for different product alternatives. Software tools and LCA databases are normally utilised to reduce the scale of the inventory collection and modelling tasks.

3. Impact assessment

Inventory flows are characterised in terms of the contribution to selected environmental indicators (CO_2 and methane to greenhouse, NO_x to eutrophication and so on). Indicator results are then calculated and may be normalised against national or international reference flows (divide indicator results by total national or international results to determine relative contributions to different indicator results). The normalised indicators may be aggregated via a weighting approach into as few as one indicator.

4. Interpretation

In the interpretation stage, significant results from the inventory and impact assessment stage are checked and evaluated to determine if the data and modelling are sufficient to answer the questions defined in the goal and scope. This includes the use of sensitivity analysis, data quality check, and consistency checks on each stage of the study.

Latest Developments in LCA

Life cycle assessment has been refined greatly over the past decade. The mainstream building industry is shifting from a position of scepticism towards LCA as too time consuming, difficult to implement and costly, to considering it useful and desirable, and actively contributing to the development of the infrastructure to support its including into decision making. For example, the GBCA's next generation of tools is expected to have significant amounts of LCA thinking to resolve conflicting messages from credits which have to date dealt independently with different life cycle stages and impacts.

For architects and building designers there are new tools, such as LCADesign, to help undertake whole of building LCA. These tools generally utilise information from CAD software to expedite the LCA process.

Tool Development

There has been an increase in tool development by product manufacturers. From spreadsheets to tools such as SimaPro, these firms are using LCA to help them with product design and development and for tendering new projects.

The growing availability of product LCA data is being aided by the increased availability and reliability to LCA data and a growing trend in product labelling, with the product manufacturing and building industries cooperating in the production and dissemination of clear, transparent data. This is largely being driven by Green Star and similar schemes, which are interrogating materials and products for their environmental credentials.

In Australia, BPIC (Building Product Industry Council) has developed gate-to-gate data (product manufacturing data) for key building materials. This data is not currently suitable for use in LCA as it does not have supply chain information, but this is expected to gain this once it has been migrated to the AusLCI database launched in March 2011 by ALCAS (Australian Life Cycle Assessment Society). The AusLCI database is a cross sector, publically available life cycle inventory data project. Currently it contains mostly energy production data, but its data sets are expected to expand rapidly over the next few years.

Carbon Footprinting

Dominating tool development is the use of carbon footprinting over the life of projects. This has driven a revolution in the life cycle domain, with many developers and investors now analysing the carbon footprint of their proposed design. The adoption of carbon footprinting and LCA methodology into quantity surveying is a good example of this.

Though it bears a strong resemblance to LCA, carbon footprinting is not LCA. It less structured. For example, the definition of boundary conditions is embedded in the use of carbon equivalent emission factors rather than being developed within the LCA. The focus is also on a single impact – climate change – and not a group of impacts. Yet it can give a good idea of the whole of life impact and helps prioritise areas of intervention, as energy is a reasonable proxy for most environmental impacts.

Attribution and Consequential LCA

In recent years, two major types of LCA have emerged. The first is based on an accounting approach which is interested in where emissions are coming from and what organisation and sectors are responsible for these emissions. This is sometimes referred to as attributional LCA.

The second approach focuses on the environmental effects of decisions, referred to as consequential LCA, or consequential modelling. In this approach, the boundary of the LCA is anything affected by the decision, design or development that is proposed. This eliminates some of the arbitrary boundary setting currently employed by attributional LCA.

In consequential LCA, the full consequences of any change regardless of the scope, the owner, the time frame, and so forth is taken into account. This means that there is scope to include positive consequences that may not be related to the initial construction of the design – for example, if a green roof is planted and it has biodiversity and stormwater advantages.

Making Life Cycle Decisions

Life cycle decisions can be defined as decisions that take into account impacts beyond the immediate context. For example, the immediate context for a decision to recycle paper might be 'where can I put this old paper?', while the life cycle context takes account of potential environmental impacts of disposal and the potential to save resources through recycling. The extent to which decision makers are able to take account of the life cycle impacts of pending decisions depends on the nature and the quality of information available.

This section provides a six-step guide on how to use life cycle information in a decision-making context.

1. Establish if LCA is appropriate

LCA will not design buildings, as it is not a creative tool. It is essentially a reactive tool to assess the impacts of potential design decisions. LCA is an iterative process which may lead a design (or decision process) in new directions. For green building projects, there are many activities to be undertaken and decisions to be made, some of which will have life cycle implications and a few of which may justify undertaking new LCA work.

2. Establish relative impact of decisions

Whether the issue is a whole building, a component, or an appliance, it is useful to get a sense of the relative impacts of the decision over the major life cycle phases:

- construction and materials
- utilisation and maintenance
- end-of-life

The use phase will often dominate the life cycle of buildings, however, the construction impacts of buildings remain significant (particularly when the building operation is optimised) and the end of life impacts can be important, especially in the area of solid waste.

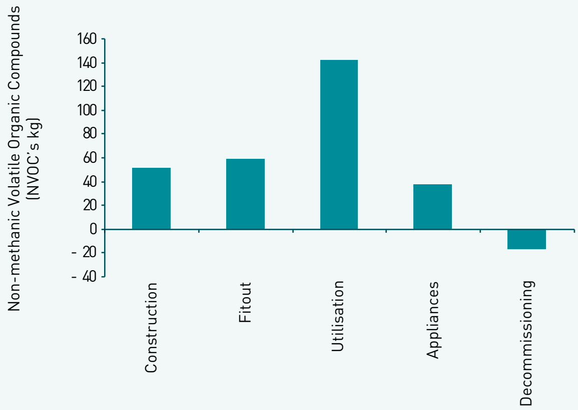

Figure 2: Total energy use over 60 year life of Fairweather home in Melbourne (Source: BHP Billiton's Minerals Technology 2002)

Figure 2, from the case study presented in the LISA software package, gives total energy impact data for typical life cycle stages for a residential building in Melbourne. It shows the utilisation phase dominating the building impacts. Figure 3 is from the same case study but shows total emissions of non-methanic volatile organic compounds (NMVOCs) and the significant contributions from construction and fit-out where large quantities of paints, glues and bonded materials are used.

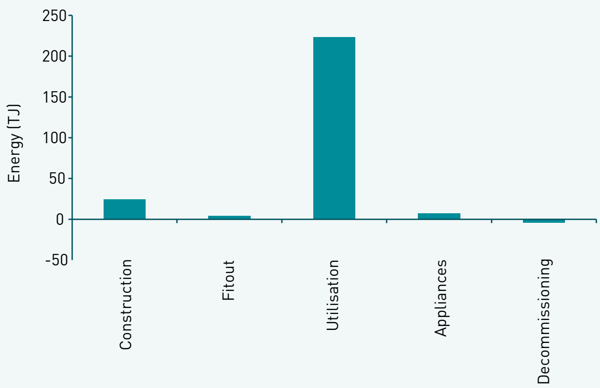

Figure 3: Total Non-Methanic Volatile Organic Compounds over 60 year life of Fairweather home in Melbourne (Source: BHP Billiton's Minerals Technology 2002)

3. Consider tradeoffs, tensions and synergies

Does your decision cut across life cycle stages – i.e. are you evaluating impacts in one stage which have significant effects in another stage? This may be the same effects – such as a less durable coating during construction will need recoating more often over the life of a building. There may be different impacts across different stages, for example, the design of a building's frame will affect the construction material used and the operational phase will be affected by the heating and cooling loads.

Does your decision cut across building elements? For example, more rigid panelling may require less intricate framing.

Does your decision cut across major environmental indicators? For example, a concrete structure may have high global warming impacts; while a timber structure may have a higher impact on biodiversity.

4. Prioritise impact areas

Identify important impacts from your perspective and from those of stakeholders involved in the decision. Energy and greenhouse impacts are important and are well documented and easy to measure. Energy also represents a broad group of impacts, including emissions of toxins and other air pollution effects, however, there are many situations where energy may not be the most significant issue. Additional impacts to be considered in the built environment include:

- biodiversity issues when utilising timber products
- indoor air quality with volatile organic compound (VOC) emissions when looking at paints, coatings, adhesives, furnishings and composite wooden products

If your decision involves comparison of products with vastly different impacts, be aware that a judgement call may be required to evaluate the importance of the two issues. For example, how energy impacts are traded off against harvesting the timber from old growth forest.

5. Choose level of analysis

The level of analysis needs to be consistent with the scale and type of decision. For occasional decisions on specific building aspects the options are:

- Work from existing studies and extrapolate to the new situation – but take care when transferring results between different climates and different regions with different energy impacts.
- Check existing design guides or other sources of data and experiences. Again, take care to account for local factors
- Undertake some streamlined environmental assessment using either a matrix approach (see Lewis, Gertsakis et al 2001) or a simple software package

For more important strategic decisions and looking at new and/or complex decisions, a more formal LCA may be required. If this is the case, first check overseas and simplified studies to establish the current state of knowledge and be clear about what new information you intend to generate that isn't already in the public domain. Clearly establish the question to be addressed in the LCA and the criteria to be used for judgement, e.g. what indicators are going to be used? Are economic costs or social issues going to be included? Decide if the decision is for internal use or if the study is going to be published. The ISO standards have special provisions for 'comparative assertions released to the public'(International Standards Organisation 1997), such as rules on the types of environmental indicators which can be used.

For larger public policy decisions, a full peer reviewed LCA should be used which follows the specifications within the LCA standard (International Standards Organisation 1997).

It is not advisable to use LCA for obvious decisions (for example to insulate or not to insulate a domestic home), decisions where there are irresolvable tensions between environmental indicators (for example, old growth timber versus steel beams) or in areas where there is a clear lack of scientific evidence, unless you are able to address those shortcomings with new information, e.g. the PVC debate where the LCA has failed to resolve apparent differences in perspective between industry and environmental groups (Tukker 2000).

6. Interpret results

Look for significant differences between decision options and identify as far as practical, why the options differ. Undertake a reality check on the significant results with the help of rules of thumb, mass and energy balances and the results of other studies. Incorporate non-numeric information on issues, such as biodiversity or social issues, with the significant numerical results to give a rounded picture of the possible environmental implications of different decisions.

When undertaking or interpreting LCA data, be aware of allocation decisions built into inventory data. Allocation is undertaken wherever a process produces more than one valuable output. The two main approaches to allocation are:

- to split emissions between the two products based on some physical or economic relationship (often by economic value)
- to provide credits to the production system for co-products, by identifying alternative ways to produce them and subtracting impacts of these alternate processes from the main production process

For example, a tree can produce both timber for building as well as wood for energy production. The emissions and resources used to produce the tree could be split between the timber and firewood based on their relative value, volume or mass. Alternatively, the building timber product could receive all the impacts of production but be credited with the alternate energy production source which would be needed if the firewood was not available.

Allocation is also necessary when considering recycling, where the recycled material generated at the end-of-life becomes a co-product of the product system. The most common approach in recycling systems is to provide a credit to the product that is being recycled, equivalent to the material displaced because of the recyclate. Examples of substitutions are: virgin aluminium when recycling aluminium products, aggregate (gravel) when recycling concrete, and virgin paper pulp when recycling paper.

There is some contention as to how to allocate the credit for recycling between the product system which supplies the material for recycling, and the product system which utilises the material in a new product. A detailed discussion of the issues surrounding this allocation problem is beyond the scope of this note, but as a general rule of thumb, for material with well established recycling industries, where all available material is fully utilised, then the recycling credit is provided to the supplier of the recycled material. Where a material has a poorly developed market and the available material is under-utilised, then the credit goes to the product system, which utilises the recycled material (see Weidema 2000 for a detailed discussion of approaches to this methodology).

Case Study: Reservoir Civic Centre

Introduction

The Reservoir Civic Centre development was put out to tender in 1999 by the Darebin City Council. As part of the council's commitment to the Cities for Climate Protection program, council required that the building be environmentally responsible. Council stated that issues of waste minimisation, energy and water efficiency and material selection be addressed. An environmental advisor was appointed to work on the project, advising the architects from the concept design phase.

The Project

The building was designed to be a community building encompassing a recording studio, youth resources area, cafe, customer service centre, maternity and health centre, function room, meeting rooms and UN room (area designated for the various community groups to write their newsletters, etc). The building comprises 800 m^2 of floor space over 1.5 storeys and the life expectancy is 50 years.

The nature of the project and the information and resources available enabled the use of a life cycle approach to support decisions on sustainability measures employed in the design. Each decision was analysed by asking three questions:

1. What are the impacts of the materials and the construction methods used?
2. What are the impacts of the decision on building performance during use?
3. What are the implications regarding the impact at the end-of-life of the building?

In an ideal world, the time and resources would be available to document the answers to each question for every decision made, but being based on a real project the most important thing was the understanding of the three questions. This was achieved, in part, through several Friday afternoon sessions with the design team where the concepts were discussed.

Once the questions were asked in relation to a specific decision, the next problem was how to compare the alternatives. For the most part, this was based on literature, expert knowledge, precedence, and in a few cases, a 'quick and dirty LCA' using standard data in a software tool (in this case, SimaPro).

The LCA Process

Apart from the use of embodied energy to determine material choice, other environmental issues influenced decision making. Decisions were supported in the design process by using the abovementioned three questions, the literature, expert advice and some software based LCAs. To illustrate the process, four very different building components and materials are discussed here:

- cladding
- flooring
- paints
- insulation

Cladding

For aesthetic reasons, certain areas of the building were designed to be clad externally. This presented the problem of choosing a cladding material that performed well, aesthetically as well as environmentally. A streamlined LCA was undertaken, using SimaPro LCA software, to compare two cladding options. This required information from the suppliers on the weight per metre squared of the material used in the cladding systems with generic data on each material being taken from the software database. The results for the two options were shown to the designers and their strengths and weaknesses highlighted. Both products had significant impacts, although in different areas, and through discussion and examination of these impacts, a third option was raised, which avoided some of the impacts of the first two, while providing the required aesthetic qualities, at a lower cost.

Data required:

- material (kg/per m^2) in each cladding system
- database with data on the materials
- transport estimation (local/international)

Tool: SimaPro

Flooring

Within the building, there is a large function hall that is designed to have a sprung wooden floor. In deciding which wood to use, the life cycle approach was adopted to guide discussion, resulting in the following list of requirements. The material needed to be:

- from a renewable resource such as a mixed plantation or fast growing species such as bamboo
- treated with non-harmful chemicals.
- finished using a low emission material that met the German E1 Standard of less than 0.01ppm of formaldehyde
- from a local source
- available in sizes appropriate to the function hall size
- durable, requiring little maintenance
- recyclable at the end of its life

The material chosen was a bamboo floor sourced from Queensland.

Data required: Information from the supplier on wood source, treatment, finishing, maintenance and sizes

Tool: Life cycle approach and checklist

Paints

Most of the building walls will be painted. It became obvious that the main life cycle issues for paint were indoor air quality and the potential impacts on human health due to paint emissions, durability and waste minimisation. The paints chosen were non-toxic, low emission and Australian made. The method of application to minimise waste was also specified. Information was readily available from paint manufacturers.

Data required:

- Information from the supplier on paint source, guarantee of non-toxicity, absence of lead and low emission
- Which walls needed to be painted and how many coats?

Tool: Life cycle approach and checklist

Insulation

In most climates, insulation is very important to allow the building's thermal performance to be optimised. Based on CSIRO modelling, insulation levels were set and a range of materials were investigated that could achieve the requisite insulation level. A mix of software-based LCA, literature, expert opinion and site requirements were used to evaluate the different options. A significant constraint was that some of the wall cavities were only 50mm wide, so that the material had to be relatively thin, but with a high R value. This provided some interesting discussion about energy savings and material choices. Based on the tools used, it was decided to use recycled plastic bulk insulation, and for the narrow cavities, a thin, high density CO2-blown expanded polymer, combined with an aluminium reflective sheet. In considering the different options for insulation, the total benefits of insulating the building were considered. Figure 4 shows that the relative energy impact of the insulation material was small compared with the energy saved over the life of the building. This meant that any differences between types of insulation would have minimal life cycle impact. In comparing the materials, preference went to those that had a high recycled content and low occupational health and safety impacts.

Data required: Information from the supplier on insulation material, source, weight per m^2, thickness required to meet R-value.

Tool: Life cycle approach, embodied energy over life cycle, expert opinion, literature

Energy and Thermal Modelling

CSIRO was commissioned to undertake energy modelling on the building design so as to gain comprehensive and a scientific understanding of the performance of the building design in thermal performance, natural ventilation and embodied energy of materials. This information was used to refine the building design, choose the building materials and the environmental control strategies.

Embodied Energy

The CSIRO produced a report on the embodied energy performance of the materials chosen and gave a list of common embodied energy figures for many materials. The list was useful as it allowed the designers to compare alternative material choices on the basis of embodied energy figures taking into account the relative performance of the different materials, and the recyclability of the materials at end-of-life.

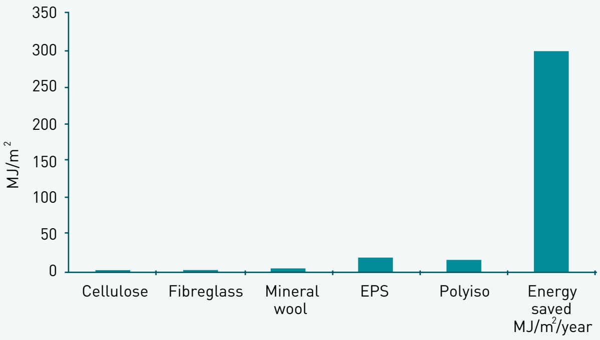

Figure 4: Embodied energy in insulation (R2) compared to energy saved over one year. (Source: Wilson 1995)

Data required:

- A list of material and their alternatives to be used in the building
- Knowledge of relative material performance specifications

Tool: CSIRO embodied energy table

Thermal Performance Modelling

Thermal performance modelling was undertaken to estimate total heating and cooling loads for a given building design in a given climate. The results were tables showing the amount of time the building would need to be cooled or heated over a year to remain within the set temperature range. Different design options were investigated to meet the objective of minimisation of auxiliary heating and cooling. For example, insulation levels and thermal mass were increased resulting in a 'reverse veneer' design with the concrete block on the inside, insulation and then either another layer of concrete block or exterior cladding. This reduced the heating load by 9% and the cooling load by 10%.

Data required:

- building plans (including elevations)
- window, door heights and sizes
- materials
- orientation and shading plans

Tool: CSIRO CHEMIX (a combination of CHENATH, the simulation engine used in the NatHERS software, and MIX Natural ventilation

Analysis of natural ventilation resulted in similar tables to the thermal modelling. The options looked at for natural ventilation were the use of night purging (blowing air through the building overnight to bring down the heat stored in thermal mass of the building) and a breezeway in the form of a roof forest.

The night purging was shown to reduce the need to cool by 24%. Another option that was discussed was to run air vents through the thermal mass of the rainwater tanks and through the building. This was deemed unfeasible however, as it was thought that the energy requirement of the blowers to facilitate this would outweigh the savings gained. Similarly, bringing air in via a tunnel under the car park into the building was discussed but not modelled as it was decided that the cost would be prohibitive.

Data required:

- building plans (including elevations)
- window, door heights and sizes, including estimation of opening and closing times
- planned exhaust fans
- orientation and shading plans

Tool: CSIRO CHEMIX (a combination of CHENATH, the simulation engine used in the NatHERS software, and MIX)

Results

The impacts of different design strategies on winter heating loads are shown in Figure 5 and can be summarised as:

- Insulation plus thermal mass would decrease the need to heat by 10% – however 54% of the time the building would be under 18°C
- Double glazing decreases heating time by 6%
- Increasing thermal mass decreases heating time by 6%

All options were compared to a base-case which was a standard tilt-up concrete and steel structure.

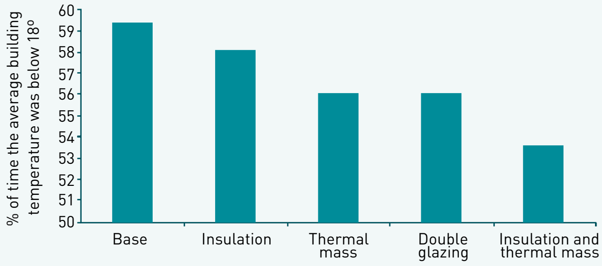

Figure 5: Percentage of time the average building temperature was below 18ºC (Source: The Cooperative Research Centre for Construction)[1]

Figure 6 shows the impacts of design strategies on summer cooling loads, which can be summarised as:

- Decreasing number of openable windows to 80 (or 50%) would worsen the base case
- Increased thermal mass and night purging would reduce the need to cool by 24%
- Double-glazing would have little effect
- Insulation on the outside of thermal mass would decrease the need to cool by over 10%

Overall conclusions are that the building will perform well in summer, only needing cooling about 15% of the time. The amount of cooling is affected by the top floor which is performing the least favourably. Since the three warmest rooms will need to be refrigerant-cooled, this should have a significant impact on the need for cooling of the rest of the building. The building will perform less well in winter, requiring heating around 50% of the time.

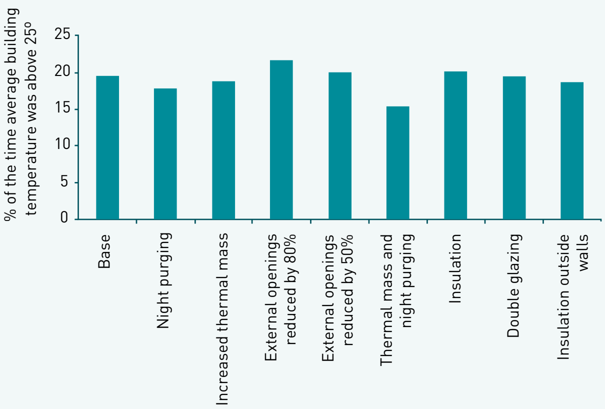

Figure 6: Percentage of time the average building temperature was above 25ºC (Source: The Cooperative Research Centre for Construction)

1 Note: Background data provided was for an extreme winter week with high wind. CSIRO modelled for a low temperature of 18ºC whereas the agreed-on lower temperature for this project was 19ºC.

Incorporation of LCA and Thermal Modelling in Final Design

The design of the building and the selection of the materials used in its construction were improved through a life cycle approach and performance modelling, by the CSIRO. A summary of the outcomes is given below.

Materials and Construction

Materials were primarily chosen on the basis of lowest embodied energy and this resulted in a concrete block construction, with structural wood used in preference to steel, where appropriate. The concrete block was specified to be from an efficient source; the wood from a certified Australian plantation if not available from recycled sources, and utilising a low-impact preservative; and the steel was specified to have recycled content, where possible.

Operational Performance

The building was designed to minimise the need for heating and cooling by making maximum use of high thermal mass and insulation, double glazing, night purging, natural light, and breezeways. Evaporative cooling and hydronic heating were chosen and the building is expected to be very efficient, performing better than a 5 star building, using the Australian Building Energy Rating Scheme.

End of Life

Materials that could be safely recycled at the end of the building's life were chosen.

Summary

In this case study LCA was used as a framework from which to make decisions, articulated through the three life cycle approach questions. In most cases, no quantitative tools were used and in every case the use of the questions needed to be flexible to incorporate the information that was relevant to the decision. For example:

- The cladding needed to meet aesthetic requirements
- The insulation needed to meet cavity size requirements
- The embodied energy analysis needed to consider structural load requirements

From this case study, it can be said that though the tools informed the choices, they needed to be flexible, dynamic and, very importantly, relevant to the architectural team.

Conclusion

LCA is ideally suited for evaluating the environmental impacts of alternative systems by comporing their material production impacts, operational considerations and end-of-life recycling and disposal.

Rather than doing an LCA for every building, however, the main use of LCA should be for strategic and significant decisions that could have far reaching consequences: i.e. chosing between different building systems. For all other decisions there will be life cycle thinking and the next generation tools of organisations such as the GBCA and Living Future Institute.

References and Further Reading

EDG note PRO 08, 'Strategies and Resources for Material Selection', Walker-Morison, A, Grant, T, McAlister, S

Crawford, RH, 2011, *Life Cycle Assessment in the Built Environment*, London, Taylor and Francis

Horne, R, Grant, T and Verghese, K, 2009, *Life Cycle Assessment: Principles, Practice and Prospects*, CSIRO Publishing, Collingwood

Department of Environment, 2006, *Scoping Study to Investigate Measures for Improving the Environmental Sustainability of Building Materials*, www.climatechange.gov.au/what-you-need-to-know/buildings/publications/~/media/publications/energy-efficiency/buildings/scoping-study-measures-improving-building-materials-pdf.pdf

About the Author

Dr Hes received a science degree from Melbourne University and followed this with a graduate diploma in Cleaner Production and a Doctorate in 2005 at RMIT University, Melbourne. She worked for Pre Consultants in the Netherlands for several years, managing SimaPro and with Tim Grant and the Centre for Design at RMIT.

email: dhes@unimelb.edu.au

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