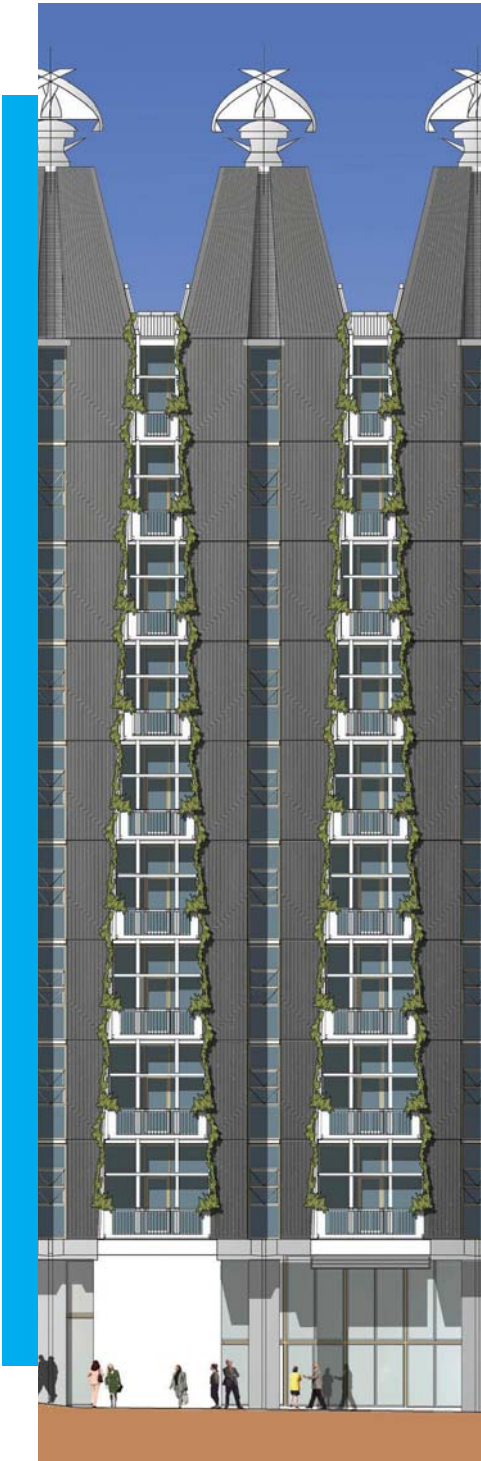


Materials Selection in Green Buildings and the CH₂ Experience



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Disclaimer

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An Australian Government Initiative



6 star rating



This rating represents World Leadership

CH₂

Preface

Council House 2 (CH₂) is a visionary new building that is changing forever the way Australia – indeed the world – approaches ecologically sustainable design.

With its Six Star Design Rating granted by the Green Building Council of Australia, CH₂ is one of the cleanest and greenest buildings on earth.

This paper, one in a series of 10 technical papers, investigates the design and systems of CH₂ prior to occupancy and availability of operational performance data. The papers have been written by independent authors from Australian universities, as part of the CH₂ Study and Outreach Program – a coordinated effort to consolidate the various opportunities for study, research, documentation and promotion generated by CH₂.

The aim of the CH₂ Study and Outreach Program is to raise awareness of sustainable design and technology throughout the commercial property sector and related industries.

While the pre-occupancy research papers are a valuable resource, they do have some limitations. For instance, these studies have been written before operational experience. This means the authors' views are based on existing knowledge, which can be difficult to apply when significant innovation exists.

Many of the innovations in CH₂ have been subject to limited, if any, rigorous or directly relevant research in the academic field, which is reflected in the lack of literature cited for systems such as the shower towers and phase change materials used in the cooling system.

Another major limitation is the exclusion, by academics generally, of industry experience of new technologies. The extensive knowledge gained by industry is often not well documented and can be difficult to access through traditional academic channels.

One example, where industry expertise exists, is the use of phase change materials for reducing peak cooling loads and energy use in commercial and institutional settings, such as offices, hospitals, prisons and factories.

In addition, to enable the authors to complete their task, they have based their study on CH₂ project reports prior to the design being finalised. This means some of the descriptions of systems and findings in the papers are to some extent out dated. In particular, findings related to the wind turbines and the heating, cooling and ventilation systems have changed somewhat as a result of final design decisions.

To reduce the impact of these limitations for readers, the Council has provided additional comment as footnotes in some papers.

It is important to inform readers the target audience for these papers is professionals and academics involved in the research, design, engineering, construction and delivery of high performance buildings. This helps to explain the technical detail, length and complexity of the studies.

Although these papers may be of interest to a range of audiences it's important that readers, who possess a limited knowledge of the subjects covered, obtain further information to ensure they understand the context, relevance and limitations of what they are reading.

For more information or to make comment and provide feedback, readers are invited to contact the Council. The details are available at the end of this document.

We hope you enjoy reading these technical studies and find they are a useful resource for progressing your own organisation's adoption of sustainable building principles and encouraging the development of a more sustainable built environment.

Foreword

In 2000 the City of Melbourne made the decision to embark on a revolutionary new project called Council House 2 (CH₂). The decision was due to a pressing need for office space for its administration and the desire to breathe life into an under-used section of the city.

The project gave the Council the opportunity to exercise its environmental credentials by creating a building that was at once innovative, technologically advanced, environmentally sustainable and financially responsible.

This approach allowed the Council to insulate itself against exposure to rising energy and water prices, the diminishing availability of resources and the uncertain long-term availability, while providing a healthy workplace attracting the best workforce in a labour-constrained market.

CH₂ has been designed to reflect the planet's ecology, which is an immensely complex system of interrelated components.

From the revolutionary cooling storage system in the basement to vertical gardens and wind turbines on the roof, the building has sustainable technologies integrated throughout its 10 storeys.

Although the majority of the technologies and principles adopted in the building are not new, never before in Australia have they been used in an office building in such a comprehensive and interrelated fashion.

This includes innovations such as: using thermal mass for improving comfort; phase change material to reduce peak energy demands and energy use; generating electricity onsite from natural gas; and using waste heat for cooling and heating.

Through CH₂, the Council plans to trigger a lifestyle and workstyle revolution. The building will be used as a living, breathing example, demonstrating the potential for sustainable design principles and technologies to transform the way industries approach the design, construction and philosophy of our built environment.

As with many revolutions, there are sceptics. The Council's response has been to patiently press ahead with the construction of CH₂ while actively and energetically encouraging lively debate.

Some of the papers in this pre-occupancy study and outreach series make compelling points in favour of the case for sustainable development. Others reflect a more subtle or sometimes overt scepticism that may be encountered throughout the community.

The City of Melbourne welcomes all of this debate but in the long term intends to demonstrate the effective performance of CH₂ and prove the doubters wrong. Collectively, the studies demonstrate the enormous value to be gained by researching the case for sustainable development and the scope for much more study and documentation in this field in the future.

The City of Melbourne wants CH₂ to be copied, improved on and enthusiastically taken up throughout Melbourne and far beyond.

Technical Research Paper 09

Materials Selection in Green Buildings and the CH₂ Experience



Andrew Walker Morison, Dominique Hes and Margaret Bates, RMIT University.

Scope

Buildings account for one sixth of the world's fresh water withdrawals, one quarter of its wood harvest, and two fifths of its material and energy flows... Building and construction activities worldwide consume three billion tons of raw materials each year or 40 per cent of total global use.

(Roodman & Lenssen 1995)

As buildings become more energy efficient and other impacts are offset through improvements in design and application, the role and impact of materials used to construct a building becomes more important, particularly over its lifespan. This paper looks at the role of materials selection and the current methods of assessing their environmental impacts.

Materials selection and assessment for the City of Melbourne's Council House 2 (CH₂) building throughout its design phase are examined to highlight issues and challenges, and how these can be resolved (to some extent). Concrete is used as an example to demonstrate the influences and outcomes of the decision making processes used in the CH₂ project.

To date, it has been generally held that operational energy requirements were by far the greatest environmental impact over the life of a building, with operational energy overtaking the energy it takes to construct a standard commercial building in as little as five to 10 years. But as Roodman & Lenssen (1995) indicate, this figure fails to tell the whole story. They point out that as buildings become more operationally efficient, the relative environmental impact of building materials used in their construction is greater again. In addition, materials have other impacts as well as energy. These include:

- habitat degradation arising from logging, mining, transport, waste dumping and pollution from various stages of extraction, production and disposal;
- erosion of natural capital through (short) one-life use of most materials;
- greenhouse gas emissions from transportation, production, installation and demolition/ disposal; and

- non-construction impacts in other areas of the economy driven by the practices used in the construction industry (e.g. waste). As the construction industry constitutes a large percentage of total economic activity in most countries, its impact stretches into other many other industries.
- CH₂ sought to establish new benchmarks in the selection and use of sustainable building materials in its construction.

This paper first considers the important role of materials selection in a building's overall environmental profile, and examines international best practice. This is followed by an examination of the strategies, directions and outcomes (at the time of writing) for the CH₂ project. These include:

- materials selection and design strategies used on CH₂;
- the design and specification process, and key issues;
- materials used for the base building;
- products and materials used in the fit-out;
- an in-depth look at a key material specification for CH₂, namely concrete;
- discussion of potential environmental benefits from the approach taken; and
- lessons learned, including the DesignInc 'CH₂ Top Ten Lessons Learned in materials selection'.

Materials – A Key CH₂ Focus

Impact of Materials on a Building's Environmental Profile

Most in-depth research on the environmental impact of construction and fit-out materials has been conducted on individual materials such as steel and timber. Published studies assessing the contribution of all materials tend to focus on embodied energy (looking at the total energy consumed to produce and transport a product). Within these studies there is a considerable range. One study found that embodied energy per m² of floor area of buildings was between four and 12 GJ/m² – representing less than five per cent of the total energy consumption of the building (Cole 1998; Cole & Kernan 1996).

Another study showed seven GJ/m² (Scheuer, Keoleian & Reppe 2003) for a six-storey university building with a lifespan of 75 years (2.2 per cent of life cycle primary energy consumption), while in Japan the materials and construction component of a building with a 40 year lifespan was 8.95 GJ/m² – 15 per cent of total energy (Suzuki & Oka 1998). Although these numbers are high, they all represent a small percentage of the total energy consumed by a building over its life¹. Table 1 below summarises studies and their findings in this area.

Study	Building Type	Findings
Suzuki, Oka, 1998	Eight buildings from 1200 – 2000m ² (concrete) with one at 8,000m ² and one at 22,000m ² (steel) in area with packaged heat pumps.	<ul style="list-style-type: none"> • Construction 6.5 – 13GJ/m² (high figures from high finish buildings) avg 8.5 Input/Output data. Operational energy 1.54GJ/m². • Renovation work min 1.0GJ max 2.6GJ/m² for 40 years. • CO₂ from construction avg 790kg/m². • Over life cycle construction =15% of 59.4GJ and 18% of 4,430kg CO₂/m².
Scheuer et al	Mixed educational and hotel building, 7,600m ² .	<ul style="list-style-type: none"> • Primary energy: total embodied over life cycle including maintenance: • 51 GJ (2% of life cycle initial 1.7%, replacement 0.3), or 7.0GJ/m². • Transportation and construction activities about 0.1% of life cycle each. • Carpet and ceiling tiles included (recycling assumed using US EPA guidelines for allocation) but not other fit-out items.
Cole and Kernan 1996	Three storey 4,620 m ² office building.	<ul style="list-style-type: none"> • Initial embodied energy range from 4 to 12GJ/m².
Buchanan and Levine 1999	Nine buildings from small domestic home to five storey office building and single storey industrial building	<ul style="list-style-type: none"> • 4.7 – 4.8 GJ/m³ for concrete or steel respectively.
Treloar and McCoubrie 1999	Melbourne office building.	<ul style="list-style-type: none"> • Furniture capital construction 1.5GJ/m² Input/Output primary. • Operational energy 8.0GJ. Embodied Energy in structure 3.13GJ. • Replacement churn items 8.4GJ.
Treloar 1996	Melbourne office building, 47,000 m ² building.	<ul style="list-style-type: none"> • Embodied Energy equivalent to half Output Energy (primary energy) Input/Output analysis. • 8.76GJ/m² Input/Output for a 47,000 m² office building

Table 1: Summary of Materials studies.

¹ The exact percentage of capital and churn EE relative to operational energy has been disputed and therefore it is possible that EE could vary between 4 and 40 years of operational energy. More research is needed in this area.

The Organisation for Economic Cooperation and Development (OECD) reported in 2002 and 2003 that buildings consume 30 per cent of available raw materials and 42 per cent of energy, generate 40 per cent of our emissions to air, and 40 per cent of waste to landfill (OECD 2002, 2003). In Australia, the built environment also accounts for around 12 per cent of our consumption of drinking water (ABS 2000). Further, the materials in a building can significantly affect human health. The indoor air level of many pollutants, the OECD reported, may be 2.5 to 100 times higher than outdoor levels. The indoor air level of pollutants is primarily emissions from fit-out materials and some building materials.

Materials should be chosen using the traditional design hierarchy of reduce – reuse – recycle, aiming for healthy indoor air, resource conservation and minimisation of waste and emissions.

What is a 'Green Building Material'?

There are various definitions of 'green' used in the construction industry, ranging from the simple to those involving detailed criteria. A good, simple definition is that green materials are environmentally responsible because impacts are considered over the life of a product (Spiegel & Meadows 1999). Depending on the project goals, an assessment of green materials may involve an evaluation of one or more of the criteria listed below (based on Froeschle 1999).

- Resource efficiency:
 - recycled content;
 - natural, plentiful or renewable;
 - resource efficient manufacturing process;
 - locally available;
 - salvaged, refurbished, or remanufactured;
 - reusable or recyclable;
 - recycled or recyclable product packaging; and
 - durable.
- Indoor air quality:
 - low or non-toxic;
 - minimal chemical emissions;
 - low volatile organic compound (VOC) assembly;
 - moisture resistant;
 - healthfully maintained; and
 - systems or equipment.
- Energy efficiency – materials, components, and systems that help reduce energy consumption in buildings and facilities:
 - supports energy efficient performance; and
 - has low embodied energy.

- Water conservation – materials, components, and systems that help reduce energy consumption in buildings and facilities:
 - supports water efficient performance; and
 - has low embodied water.
- Affordability – fits within budget looking at the long term.

General Techniques for Assessing Materials

There are many international guidelines and techniques to assess materials for their environmental credentials, but no specific overall standard has yet been developed (Berge 1997; Woolley & Kimmins 2000; Anderson et al. 2002; Curwell 2002). One of the most rigorous methods is Life Cycle Assessment (LCA), a method for assessing the impacts of a product over its lifespan including all its measurable inputs and outputs. While LCA is a useful tool there are issues it fails to resolve. The first is with the reliability and extent of data on which assessments are based. Studies on materials are either relatively accurate but are confidential and take considerable time and resources to conduct, or they are more generic and less accurate. Another problem is the amount of time and the cost of conducting an LCA, which is beyond most building projects. A third problem is that while LCA is strong at estimating readily quantifiable materials flows, such as in a manufacturing process, it fails to include important impacts such as biodiversity loss and habitat degradation. Often manufacturers take on the expense of an LCA to make their product stand out and improve their production processes.

Due to these complexities, projects rely on less complicated indicators such as embodied energy, material intensity per service unit (MIPS) or footprints (total land used to produce a product). However, these indicators tend to consider only one or a limited set of indicators, such as energy and land used, whilst ignoring other crucial impacts such as toxicity. Embodied energy figures are also typically based on capital accounts that include all the costs associated with a product and allocate an energy conversion factor. This does not reflect actual energy used to manufacture a product and is often very large as it can include the relative cost of financing the transport company carrying the product and other costs. On the other hand, using embodied energy based on national accounts does simplify the process of collecting information because financial data is readily available on all products and processes.

Another method of simplifying the LCA process is using aggregation tools based on LCA but which provide results in simple aggregated scores. Some examples of aggregation tools are the European EcoIndicator used in EcoQuantum (housing environmental and costing tool), and EcoIT (material selection of industrial design), cost (first and future costs) and Building for Environmental and Economic Sustainability (BEES) which assesses environmental impacts (see Figure 1).



Figure 1: BEES results page.

The main problem with this type of tool is that data behind it is often hidden and it is difficult to add new data if the product being considered is not listed. The lack of uptake of BEES is highlighted by the fact that no updates have been performed since late 2003.

Yet another simplified method to support decision making on material selection is the labelling of products. No internationally successful program for labelling construction material has been achieved yet, despite several attempts.

The main problem with labelling construction materials is that they differ from location to location. Greater success has been achieved using specification or material choice support tools such as Ecospecifier and the US Environmental Building News, and guidelines such as the Aurora Material Selection Guideline and the US Federal Government's environmentally preferable purchasing (EPP) database. The US Federal Government defines an Environmentally preferable product as:

... goods that have a lesser or reduced effect on human health and the environment when compared to competing products that serve the same purpose. Environmentally preferable attributes include reduced toxicity, the use of recycled materials, and increased energy efficiency.

US Environmental Protection Agency, 2004

Labelling of materials is almost always completed by a third party independent from the manufacturer or its professional organisations, and usually includes some kind of certification. For example, the Forest Stewardship Council certifies the certifiers (SmartWood and Scientific Certification Systems – SCS) that assess whether forestry companies are using sustainable management practices to harvest wood.

In the USA, GreenGuard certifies products that meet strict indoor air quality criteria. The Energy Star label is an international standard which identifies equipment and appliances that meet or exceed standards for energy efficiency. In the US, there is also the water 'A-rating' label indicating water efficiency (Global Green, no date). In Australia, an overall building rating called Green Star was developed and implemented by the Green Building Council of Australia.

Rules of Thumb for Material Selection

While it is difficult to assess material environmental performance, there are basic ways of achieving good environmental outcomes with careful selection. The following are some rules of thumb.

Healthy indoor air:

- specify low emission water based paints;
- specify lowest formaldehyde content fibre boards;
- investigate flooring options;
- investigate the best heating/cooling solutions (which will need to be integrated with the building design from the beginning).

Resource conservation:

- specify materials with recycled content;
- specify alternatives which reduce the amount of material normally used (i.e. 'I' shaped beams).

Minimisation of waste:

- check with suppliers if they have a recycling scheme for leftover material and packaging.

Minimisation of emissions:

- encourage and facilitate the use of public transport and alternate forms of transport (i.e. bicycles).

'Best Practice' International Case Studies

Best practice in green building involves developing a fully incorporated design and management plan that integrates green design, materials and amelioration. Best practice in green material selection involves life cycle awareness of the impacts of a material, and additional impacts and the consideration of relative benefits compared to alternatives.

An increasing number of publications attempt to educate consumers and professionals about green materials and who is supplying them. While there is desire in the industry to manufacture or select green materials, there is also general frustration at the lack of a regulatory body or tax incentive for doing so.

Moves Toward Tax Incentives for Green Material Selection

In 2000, New York became the first state in America to legislate tax incentives for the building industry to use environmentally preferable materials and adopt green practices on a larger scale. The green tax credit enables builders to claim up to \$3.75 per foot (interiors) and \$7.50 per foot (exterior work) for work which meets energy goals and uses environmentally preferable materials

Natural Resources Defense Council, 2002

Therefore, green building is still largely a domain for committed individuals and organisations, where the business case shows financial gains in terms of increased productivity from a healthier building, and greater return on investment from energy efficiencies. The following national and international case studies illustrate the type of tools and rationalisation that other projects have used.

Australia

Nationally, examples of completed green building projects demonstrating best practice are the Sydney Olympics precinct and the leading '60L' green commercial building at 60 Leicester Street in Melbourne. These projects are notable for their innovation and incorporation of the latest green principles from the micro to the macro.

Materials Selection at the Sydney Olympics

The Sydney Olympics precinct integrated various sustainable building techniques in the design and construction of facilities and management of the sites. The vision of a Green Olympics was set out in Environmental Guidelines for the Summer Olympics 1993. As part of the tendering process, design teams, developers, contractors and subcontractors were asked to respond to these guidelines. The tendering process began when little was known in the industry about implementing ESD. The overall lesson from the process was that minimum environmental standards or benchmarks need to be included in the tender, at the very beginning of the project.

The main tools used for material selection during the design and construction of Sydney Olympics facilities were LCAs and questionnaires for manufacturers. Materials selection for such a high profile event encouraged manufacturers to develop greener products as this also helped develop market awareness. Trialling of new materials also took place, such as low VOC paint and cellulose insulation. The Olympics also highlighted the need for systematic application and supervision of the material selection process, as it wasn't applied as rigorously to the construction of the velodrome (Green Games Watch 2000).

60L – 60 Leicester Street, Carlton, Melbourne

The 60L building is a leading example of a commercially viable building that has successfully incorporated environmentally sustainable building practices with commercial realities through its green lease. The 60L website (www.60Lgreenbuilding.com) highlights the key principles that guided the development and actions on materials:

- The original building on the site was not bulldozed but was partially dismantled so that existing materials could be re-used. Timber floor joists and planking were re-used, as were bricks, glazed partitions and most of the old building structure, as well as the heritage listed facade;
- Concrete poured at 60L was made using a 60 per cent recycled aggregate (in this case, crushed concrete reclaimed from other buildings);
- Timber windows and door frames were fabricated from recycled materials, as were other items such as reinforcing steel and carpets (recycled synthetics);
- Most glues, adhesives, sealants and fillers commonly used in buildings emit highly toxic gases. Use of these was minimised wherever practicable;
- 60L uses about 50 per cent less PVC than a typical commercial building of the same size and use. PVC was eliminated from all water and wastewater pipes, electrical conduits and light fittings;
- Where new materials needed to be used, preference was given to recycled and recyclable products such as bricks, timber, steel and copper. (Green Building Partnership, no date).

International

For a building to be truly sustainable it must have a minimal environmental impact. A lot of the international focus is on how to push sustainable building to a lower environmental impact. The target that many projects are trying to reach is that of zero net emissions. This means any emissions produced by a building are either incorporated back into its systems and/or offset through tree planting programs and other initiatives. There are also the concepts of zero waste and zero energy.

BedZED – Beddington Zero Energy Development UK

One international best practice building developed under these principles is the UK's Beddington Zero Energy Development. BedZED is a mix of work and housing space designed and built to be energy efficient and environmentally friendly. The design of the building successfully integrated sustainable practices throughout. Energy is only sourced from renewable energy onsite, with the key aim to be sustainable within constraints of a social housing budget. Through careful selection of building materials BedZED was able to reduce their environmental impact by 25 per cent (BedZED, 2001).

Product choices were weighed up between cost implications, environmental performance and local availability. The aspects of environmental performance taken into consideration included:

- embodied CO₂;
- embodied energy;
- eco footprinting;
- ecoPoints; and
- BRE (British Research Establishment) Environmental Profiling (BedZED, 2002).

Results were then assessed, following the approach described in the case study below.

Herman Miller MarketPlace USA

Materials and Resources

The goal of the project was to achieve the highest possible Leadership in Energy and Environmental Design (LEED) rating. As a result, the specification book included the following codes and standards:

3.02 Codes and Standards

A. Comply with LEED Materials Credit 4 requirements:

Use materials that contain minimum 20 per cent by weight post-consumer recycled content or 40 per cent by weight post-industrial recycled content.

B. Comply with LEED Materials Credit 7 requirements:

Use a minimum 50 per cent of wood-based materials certified in accordance with the Forest Stewardship Council guidelines for wood building components.

C. Comply with LEED Materials Credit 5 requirements:

Use building materials that have been manufactured within 500 miles for 20 per cent of total materials.

Of those 20 per cent, specify at least 50 per cent that were extracted, harvested, or recovered within 500 miles.

Our commitment to sustainable materials was woven throughout the specification book. Each section featured an 'environmental considerations' topic addressing specific, relevant environmental concerns.

As an example, the following addresses concrete forms:

Environmental Considerations

A. Problems:

Wood used for formwork contributes to irresponsible forest management practices.

Wood used for formwork ends up in landfills.

B. Recommendations:

Use non-wood forms made of recycled materials.

Use wood forms from certified sources.

Use salvaged wood.

Re-use form lumber for framing and sheathing.

Use locally produced materials.

The project earned exemplary performance credit in LEED for both recycled content and regional materials. Site work included 100 per cent post-consumer recycled crushed concrete. Concrete rebar was 100 per cent recycled. Structural steel was 90 per cent post-consumer recycled. Metal joists, floor deck, and roof deck were all 95 per cent post-consumer recycled.

Green Products Used:

- natural linoleum flooring
- recycled-content acoustical ceiling panels
- recycled-content carpet tile.

Green Strategies:

- Design for materials use reduction:
 - group or stack bathrooms and other water-using spaces
 - minimise space devoted exclusively to circulation
 - consider the use of structural materials that do not require application of finish layers
 - consider exposing structural materials as finished surfaces.
- Toxic Upstream or Downstream Burdens:
 - use true linoleum flooring.
- Greenhouse Gas Emissions from Manufacture:
 - use concrete masonry units with fly ash replacing a portion of the cement.
- Post-Consumer Recycled Materials:
 - prefer insulation with high recycled content
 - specify heavy steel framing with highest recycled content
 - specify carpet tiles made with recycled-content backing.
- Transportation of Materials:
 - prefer materials that are sourced and manufactured within the local area.

Source: Office of Energy Efficiency and Renewable Energy, 2003.

CH₂ Selection and Design Strategies

The CH₂ building was designed by a multi-disciplinary team lead by the City of Melbourne's principal design architect Mick Pearce and local architectural firm DesignInc Melbourne. Construction on CH₂ started in 2005 and is due for completion in mid 2006. Confirming its achievement of ecological sustainable design objectives, the building has achieved a six star rating under the Green Star – Office Design (v1) rating tool.

The Brief

Melbourne City Council's brief for CH₂ included the following parameters:

- the building is to be a lighthouse for future City developments;
- It is to provide a comfortable, adaptable and stimulating working environment for its users, the staff of Melbourne City Council;
- It is to be seen and understood to respond to its natural as well as its social environment and to make use of resources bearing in mind the efficient use of embodied energy both in the choice of materials and in the process of their use;
- It should maximise the use of renewable energy within the bounds of present technology by harvesting sunlight, wind and rainwater together with the complexities of the Melbourne climate, and by following these principles the building should reduce CO₂ emissions to almost zero;
- It should also provide at least the same area of green cover as its footprint, bearing in mind that this area can be measured vertically as well as horizontally; and
- Finally, as a work of art, the building should inspire a new relationship between the City and nature.

One of the outcomes of the early briefing process was the development of a 'comprehensive materials assessment process' that aimed to consider key environmental aspects of a material but with three overarching priorities:

- use and adherence to the principle of lowest lifecycle cost for the anticipated 100 year life (i.e. maximising durability, minimising replacement, maximising maintainability);
- minimising embodied energy; and
- use of locally grown, sourced or manufactured products and materials.

The Central Role of Materials from the Charrette stage

A 'comprehensive materials assessment process' was first explicitly addressed following the three week design charrette at the start of the CH₂ project. The architectural design process typically starts from preliminary or schematic design, literally the schema or rough placement of spaces and shapes, through to design development, where buildings are typically drawn to scale and resolved in some detail, to contract documentation, which involves the documentation of the project in all respects to allow its construction.

Materials selection, even in 'green' projects, is often considered at the design development stage, or even contract documentation phase. A combination of aesthetic/functional/cost drivers and the designers' familiarity with broadly available products drives implicit and explicit decisions: 'I know we can do this in brick, this in steel and this in timber.' The exact specification is typically resolved towards the end of the design process.

However, this standard process can carry a high cost as it limits ESD to the ecological impacts of individual building materials. For example, it is common industry practice to use plasterboard or fibre-cement sheeting to line the walls of most modern buildings. This practice allows cables, pipes and services to be routed over the building structure but hidden by the wall and ceiling finishes. However, this can eliminate opportunities to use the effective thermal mass of a concrete structure. A completely different design of services and construction is required for a concrete structure as the finish. This is not something readily performed after schematic design. It also fails to consider the life cycle impacts of these lining substrates and a raft of practices implicit in their use, such as replacing and repainting surfaces that are easily marked and abraded.

The process used by the CH₂ design team aimed at reversing the way materials and ESD are dealt with in construction.

Step 1: Synergy, Honesty and Simplicity in Materials

In the initial charrette stage of CH₂ the design team presented a proposal for discussion and constructive criticism that used a concrete structure as an extensive thermal mass and pursued synergy, honesty and simplicity in materials used:

- Synergy: obtain multiple benefits from a material. For example, by using the structure as a thermal mass and durable finished surface.
- Honesty: use materials for their aesthetic and other intrinsic properties, seek not to clad, coat or hide them.
- Simplicity: simple is better than complex. Monolithic materials are easier to maintain, repair, and recycle than laminated, glued, composite products.

This approach, according to DesignInc, strongly influenced from the outset the design team's philosophy and aesthetic for CH₂ to be radically different from many contemporary 'Grade A' commercial buildings. It would be the genesis of innovative thinking that resulted in a striking selection of materials and finishes throughout the project.

Step 2: A Planned Approach to Materials Research and Specification

The consideration of specific materials were not raised in the initial charrette: only that whatever materials were selected needed to be in keeping with the design philosophy and adhere to the requirements of the brief, including minimising embodied energy, life cycle costs, and general environmental preferability.

The next part of the process was developing an approach to put these ideas into practice. In 1999 very few tools were available to the design team to aid their research. Ecospecifier was in its earliest days of development and had only 80 products listed. There were no other local resources available. DesignInc was left with only one option – to personally undertake the enormous research task of vetting all potential products and materials that might be used on the project.

A rolling research and development program was designed, commencing in 2000. The key elements of this program were to:

- i. establish a methodology for side-by-side comparison of products through the environmental performance questionnaire (EPQ), discussed below;
- ii. establish a peer-review process to ensure transparency and accountability, and limit liability, through the involvement of the Commonwealth Scientific Innovation Research Organisation (CSIRO);
- iii. shortlist potential products and issue the questionnaire as a condition of consideration to suppliers for completion. There would be ongoing issues of the EPQ to other suppliers throughout the project as relevant;
- iv. establish in-house systems that would enable effective storage, referencing and use of data through easy access and inter-personal communication; and
- v. integrate data into effective decision-making in the project in a timely manner through coordination and project reviews.

DesignInc used a slightly modified Environment Australia 'environmental performance data sheet' (EPDS) as their environmental performance questionnaire (EPQ) to generate standardised responses from suppliers. Questions asked by the EPDS/ EPQ include:

- the type and relative contributions of different materials in the product;
- the energy required to make the product in its various manufacturing stages, and the energy source;
- whether the product contained, or during production emitted, any of a list of chemicals listed by the Australian National Pollutant Inventory; and
- the projected lifespan of the product and the ability to repair it.

These responses were provisionally reviewed before being forwarded to the CSIRO for scoring. The CSIRO team was asked to develop a scoring system and, from the responses to the EPQ, award each product a final score.

The CSIRO method was as follows:

Step 1 – The material assessment was carried out on (1) product-manufacturer or product-supplier responses to a set of questionnaires on product composition and manufacturing, and (2) considered opinions of CSIRO experts. Neither of these on its own was considered to be sufficient to calculate the ratings.

Step 2 – The comparative ratings of products within each category/application were used as an initial guide to product selection to narrow the options for a specific project application. The ratings were not used as a substitute for more detailed investigation by the project team and expert consultants and/or specific testing of product attributes by experts, which may still be required in some cases in making a final selection.

Step 3 – The ratings were made by expert input and qualitative information where available within each category/application for each product property or attribute under a specific context of use (considered a 'standard' condition). For different conditions and context of use it was acknowledged that performance might vary. As such ratings were comparable only within categories/applications. The table was meant as an initial guide for quick comparisons of product attributes across a range of areas.

Step 4 – The products were not categorised as either bad or good; that is, a single composite rating was not given. A range of important attributes for sustainable performance (i.e. 'friendly' to people and environment) were considered. For comparison and selection, project clients and design teams were encouraged to consider the relative importance of each attribute in a particular project (i.e. the sense of relative importance of each attribute for each product category may vary from project to project).

Step 5 – Where appropriate, good performance was identified/noted. Where the rating for a product attribute was not satisfactory, the intent was to note it to encourage improvement in this area.

An example of a product scoring sheet is provided in Table 2 (used with permission from CSIRO).

Category/ Application	EPQ Ref. No.	Attributes								\$ range	Aus. Made (Y/N)	Comment
		EE	Emb. water	Wastes & Recycling	Air, Land & water emissions	Indoor emissions	Other Env impact	Service Life (w/out maint.	Maint. Req.			
Glazing	GL.xx. xx	3	1	3	2	3	2	2	4			

Legend: 4 Superior; 3 Good; 2 Average; 1 Poor; 0 Not acceptable; – Insufficient information.

Table 2 – Example score sheet.

Challenges in Implementation

Gathering Data

The first challenge for implementing this process was getting manufacturers and suppliers to complete and return environmental performance questionnaires (EPQs). Despite the fact that their completion was a condition of consideration, the questionnaires were highly technical and beyond the experience of many individuals and organisations who received them. About 50 per cent of suppliers did not respond. About 30 per cent of all EPQs issued or requested were fully completed.

To address this problem later in the project, DesignInc designed and issued a simplified three-page EPQ towards the selection of fit-out materials. Up to 80 per cent of suppliers returned the document completed. DesignInc's project architect, Claude Bertoni, believes other factors also influenced the uptake of the second EPQ, including that by this time the project was better known and the supply sector in Australia had improved significantly with regard to ESD³.

While there was a product ESD-claim declaration sign-off as part of the questionnaire, there were concerns about the quality of the data given as expressed by Bertoni: "My major fear has been relying on a manufacturer's word. I would put at the top of my wish list independent accreditation of products to give peace of mind"⁴.

Ultimately it was the CSIRO that needed to make sense of complete, partial, or contradictory data and supply project recommendations. Principal research scientist, team leader EVERGEN, CSIRO, Greg Foliente, described how this issue was resolved:

"When a manufacturer is not capable of answering those questions, it shows their environmental credentials. We shouldn't water it down, because it would break the process. Secondly, even though some of the questions are not filled in, we ... are relying on expert opinion. Once we know the raw materials and what the product is, we can guess what goes in between. It's inexact, but we know enough about the industry. Give us a few parameters here and there, and we develop a feel. Then the experts come in with the rest. As long as we are consistent, the idea is that they are always rated next to each other, and as long as you have that, it is okay."

³ Interview with Claude Bertoni, DesignInc 24/01/2005

⁴ Ibid.

⁵ Interview with Greg Foliente, CSIRO 9/06/2004

... we wanted to preserve the integrity of the RMIT effort. Also we knew [the EPQ] wouldn't be sufficient anyway. So the idea was to use it as base information. Then we relied on the expert judgement of people in CSIRO who are familiar with the issues... This is an informal process we adopted within the EVERGEN team."

On-site Substitution

Substitution of materials during construction using non-specified products is a problem endemic to the construction industry. Over the years, various contractual clauses have been developed to limit this, including clauses such as 'Taps to be (x) or similar approved', where approval is by the architect or other person nominated. All approaches however are far from ideal. The designers' control is largely eliminated in many contracts

when the project is passed to the builder. In many instances, subcontractors simply use non-specified materials, hoping to 'get away with it' on the project.

DesignInc proposed a strategy to avoid this problem:

- i. The builder's Environmental Management Plan should contain provisions requiring that no substitution is permitted unless the proposed product has undergone independent vetting using the EPQ and subsequent vetting, and is shown to be equivalent to the originally specified product. The architects have 10 days on receipt of such documentary proof to permit or refuse the substitution.
- ii. If the architects reject the proposed substitution, no impact on the program is permitted. The onus is on the builder not to propose substitutions unnecessarily, and if it not approved any lost time through delay or scheduling is their responsibility. This creates incentive for the builder to thoroughly assess all products well ahead of time.
- iii. The builder deposits a 2.5 per cent Bank Guarantee as security against making good required by the architect due to non-permitted substitutions.

In the end, points (i) and (ii) were included in the contract. Point (iii) was considered too onerous during contract negotiation and was not included.

The Influence of 'Green Star'

The introduction and launch of Green Star by the Green Building Council of Australia in 2003 marked the start of a whole new learning curve for the CH₂ project team. Having substantially designed the project, the team now needed to ensure it would meet the highest levels established by the new rating tool. Green Star attributes a relatively modest 15 per cent of available credits for the base building materials, and this focused the attention of the project team on meeting relevant requirements: reducing PVC use; avoiding the use of rainforest and old-growth timber; and using recycled content in concrete and steel. Table 3 identifies the Green Star credit and the actions taken to ensure CH₂ complied as closely as possible.

Green Star Credit	CH ₂ Response
Up to two credits for use of post-consumer recycled steel	Use of 100% post-consumer reinforcement steel from Smorgon Steel. No other recycled steel products could be identified for the project.
Up to three credits for use of high-supplementary content (cement replacements) in concrete	Development of matrix with up to 60% replacement depending on stress grading and curing speed constraints. Refer Case Study.
Up to three credits for use of sustainable timber	Use of plantation timber products. Use of recycled timber for louvres. Use of FSC-certified timber. Use of responsibly sourced timber with source documentation for window frames*.
Up to three credits for reduced use of PVC	Use of HDPE for most water and other pipework. PVC used for stormwater pipes. PVC used for power, data and communication cables.

* A contentious product that generated significant debate during the project's construction.

Table 3: Green Star – Office Design (v1) and CH₂ materials (Green Building Council Australia, 2004).

ESD Priorities at CH₂

Within this assessment the following issues were specifically examined for particular material categories:

Minimising Indoor Air Pollutants by Specifying:

- low VOC paints;
- low VOC carpets;
- low VOC adhesives and sealants; and
- all composite wood product is low emission formaldehyde.

Recycled Content of Structural Concrete:

All efforts were made to maximise the use of recycled content in the structural concrete elements of CH₂. As the concrete was mostly pre-cast, the challenge was to work with suppliers to achieve the aim of recycled concrete aggregate and replacement of cement with industrial waste such as fly ash and slag. Structural engineers, Nat Bonacci and Roger Sykes from Bonacci Group, were interviewed about this issue. They said the target was useful but they needed to work with manufacturers to ensure other requirements such as strength and appearance were met. They could achieve the overall target, but some elements would contain more recycled content while others would contain less, depending on their functional requirements⁶.

Recycled Content of Structural Steel:

The Green Star process highlighted the difficulty of obtaining necessary information when making key decisions on materials. To meet the project requirements of one particular Green Star credit point, recycled steel had to be sourced. No guarantee from local steel manufacturers could be given that 30 per cent recycled content was achievable. To meet this requirement the project team needed to look outside Australia. The steel for CH₂ was subsequently imported from Thailand.

PVC Minimisation:

In the construction of CH₂, all effort was made to minimise the use of PVC, which has a high off gassing component, is not readily recyclable and has a manufacturing process with high environmental impact. Substitution has been achieved for all hydraulics and for the data and power cabling.

Sustainable Timber Selection:

More than 90 per cent of the timber used in CH₂ is from recycled or certified sources. The main issue with achieving this score was the transparency and validity of certification processes. Some certification schemes, due to their recent introduction to the market, are not as well received or supported by stakeholders as others. Refer to 'Lessons learned' below for additional discussion on this item.

Materials Use in the Base Building

Approach Taken

CH₂ project architect, Chris Thorne, summed up the CH₂ materials selection in three words: concrete, steel, and timber⁷. While this may be something of a simplification, it captures in large part the character and tactile quality of the building if we add an additional key ingredient – abundant internal and façade-integrated vegetation. As already noted, the design philosophy for CH₂ was to derive multiple functions and benefits from well thought out use of materials and details. The extensive use of exposed concrete is one well-explored example of this. Table 4 summarises the dominant materials used on the CH₂ project.

Unfortunately it was not possible to undertake a cost-analysis for this chapter, which would be a major study in itself. Several elements are clearly non-standard and arguably of a higher specification than might be expected in comparable buildings. For example, the use of a very high specification low emissivity glass in all façade windows. The architects observed that the interconnectedness of the building as a functional system, multi-purposing of all elements, and the use and importance of their physical characteristics, made 'cost-saving' substitutions or deletions extremely difficult. For example, in the case of the façade glazing, the use of a lower specification glass would have resulted in re-sizing the mechanical plant and redesigning the building climate control systems – in effect re-thinking the whole design.

Cost discussions, Chris Thorne notes, were “occasionally quite fiery; there were high cost elements to resolve that had never been costed before such as the façade system, precast floor panels, turbines, and the western louvres⁸.” During the project, costs were managed by the Quantity Surveyor (QS) in conjunction with the client, the City of Melbourne. Rather than having a cost target, the design team was asked to use their experience and expertise to develop several options for a situation to aim for cost-effectiveness, which would then be costed by the QS.

Item/ Location	Material, Supplier	Comment
WINDOWS AND DOORS		
Window frames above ground floor.	Timber. Miglas. Ecoselect	Timber was chosen on the basis of being a product with low embodied energy and well understood performance and maintenance regimes.
Finger-jointed construction for less waste. Windows were designed for repair and disassembly (screw construction) and have an anticipated 100yr+ life.		
Refer to 'Lessons learned' further in this document. There were several challenges in finding 'eco' timber.		
Window frame, façade (west elevation only behind timber louvres)	Aluminium. Capral.	The architects decided to use a broad palette of materials. Some cost savings were available by using aluminium in this instance.
Vertical pivot louvers to west facade	Dressed recycled timber. Kennedys (Brisbane)/Nullabor (VIC).	Recycled was the preferred timber source.
Window frame, shopfronts	Timber. At the time of writing, the product was likely to be Forest Stewardship Certified 'sustainably managed hardwood'	Refer to 'Lessons learned' further below. Warping and twisting was considered a lower risk issue at ground level, and the initial preference was recycled timber. This proved too expensive.
FORMWORK		
Formwork, level 1 Slab	Plywood with Class II face. Species unspecified.	Reuse intended. For level 1 slab (biggest area) all new plywood. Plan to reuse on the job, if possible. Other areas of exposed slab to be Condeck with steel edge beam. DesignInc takes into account class very carefully as this dictates type of formwork to be used. Plywood for ground floor reduces embodied energy. Wood float finish only for upper floor slabs.
Formwork, in situ concrete generally	Lost-steel formwork eg. for upper level slabs. Condeck.	ESD benefit from use of integral finish
Formwork, precast panels	Steel. Standardised panels and modules for reuse of formwork	ESD benefit from use of integral finish

Table 4: Base Building Key ESD Materials Schedule.

⁸ Ibid.

Item/ Location	Material, Supplier	Comment
SLABS AND PANELS		
Floor slabs	In situ concrete. 20-60% use of supplementaries. Boral Concrete.	Refer Case Study. Typically 'East Coast' flyash, depending on application. Class II finish. Boral; Blue Circle.
Infill and panel elements	Precast concrete panel. Approximately 20% use of supplementaries (typically 'East Coast' flyash), depending on application. Class II finish Concrete class II finish. SA Precast; Unicrete; Fabcon.	Refer Case Study.
INSULATION		
Roof insulation	Expanded Polystyrene + River Stone over.	Topped by a timber deck to allow high levels of traffic.
INFILL WALLS		
To basement levels, but replaced with speedwall (modular, quicker reduces trades on site)	Originally blockwork, replaced by Lanscom Speed wall' a fire rated walling, an aerated concrete modular system using a steel skin.	Substitution on the basis of speed and reducing trades required on-site. There was no specific ESD advantage to the Speedwall identified.
EXTERIOR CLADDING		
Steel, sheet	Galvanised and perforated steel. Zincalume panel rib profile. Atlas Steel; Fielders; Lysaght	Steel was selected as a lower embodied energy product than aluminium, good durability, and more recyclable than composite panel systems.
Steel, Structural (eg. life core, external stair, winter gardens all exp column and beam construction)	Hot-dipped galvanized. Various suppliers.	Construction carefully detailed to allow on-site modular bolt-assembly to minimise welding and maximise galvanic integrity. Selected for durability, relatively low embodied energy, recyclability, some recycled content.
Precast concrete	Precast concrete panel. Class II finish Concrete class II finish. SA Precast; Unicrete; Fabcon.	Approximately 20% use of supplementaries (typically 'East Coast' flyash), depending on application.
Glazing (North facade)	Double-glazed clear float. Twin glaze Solarplus. G. James. Low e 'LE54' on clear. 6.38mm Lam/19 air space/6.38mm Lam, on clear.	Significantly reduces heat load and glare to building interior.
Glazing (South facade)	Double-glazed clear float. Twin glaze Solarplus. G. James. Low e 'LE50' on clear. 6.38mm Lam/19 air space/6.38mm Lam, on clear.	Significantly reduces heat load and glare to building interior.
Vertical translucent windows to external east wall east core toilets.	Cellular polycarbonate sheet.	Driven by durability, detailing wise cheaper than glass. East core is naturally ventilated.
Vertical screens	Dressed recycled timber. Kennedys/Nullabor.	
Timber window joinery	Vic Ash hardwood. Victorian State Forestry	Refer to 'Lessons learned' further below.
Horizontal wall slats	Dressed recycled timber. Kennedys/Nullabor.	
Fibre Cement Sheet	To rear of Turbine housing assemblies	
External horizontal light shelf canvas blinds and internal blinds.	PVC-impregnated fabric. Reflex shading.	The team investigated canvas, but found nothing sufficiently dimensionally stable.
North and south sides of lift shaft	Steel sandwich panel with Colorbond profile and HCFC foam core. Robertson.	Checked to ensure CFCs not used.
Tensioned S/S wire rope and fittings	Stainless steel. Ronstan.	Durability critical in this application as maintenance very difficult.

Table 4: Base Building Key ESD Materials Schedule.

Item/ Location	Material, Supplier	Comment
FLOORING		
Access flooring	Filled steel sandwich panel stringer less system. Tasman access flooring. Sandwich panel, stringer less system (supported on corners, set up posts only).	Less setout without stringers and easier setout and also no net sideways force. In conjunction with concrete slab allows effective 'harvesting' of thermal mass
Open roof deck	Dressed recycled timber. Kennedys/Nullabor.	
ROOFING		
Profiled sheet steel roofing	Zincalume/Brownbuilt 305 0.70mm thick. Atlas Steel; Fielders; Lysaght.	Selected for durability, relatively low embodied energy, and recyclability.
PIPES AND WATER RETICULATION		
External Downpipes	Hot-dipped galvanised steel. Atlas Steel; Fielders; Lysaght. On the ground floor all downpipes Rectangular Hollow Sections to prevent vandalism.	
Hot and cold water pipes	HDPE, ABS and Rehau depending on mechanical or hydraulic use.	Decision was made on the project to reduce use of PVC as far as possible. While usually cost-prohibitive, HDPE was costed as an integral element by the services engineer from early stages.
MISCELLANEOUS		
Data & Communications cabling	Halogen-Free only used.	
Internal light shelf	Perforated sheet steel. Inorganic zinc rich silicate coating. Richardson Pacific.	
Laminated opaque glazing	Glass. DMS/Pilkington.	Project used very high specification low e coatings rather than tinting.
Tinted Timber Coating System	TBC, probably Wattyl Solarguard for above ground. Sikkens for ground floor.	Sikkens would not provide a suitable warranty on finger-jointing so was not used on upper floors.
Anti graffiti sealant to concrete	TBC, probably Dulux Acratex Graffiti Clear (sacrificial) or Acrathane Clear (permanent).	
Cement render system (back of turbines)	TBC. Parbury Renderroc FC.	
Shower tower wall	ETFE membrane. Birdair Shade Structures/Covortex.	Doesn't trap heat like glass. Extremely transmissible and recyclable. Melted from a big block. Sheet doesn't degrade at all. No PVC.

Table 4: Base Building Key ESD Materials Schedule.

Materials Use in the Fit-Out

Approach Taken

The most striking characteristic of the CH₂ fit-out is how few products and materials it uses. Design team member, Juliet Moore, explains this was the intention:

“We wanted to create a striking fit-out that was beautifully finished and detailed, but achieved it through using less materials not more. Simplifying wherever possible, even if this meant thinking way outside the square.

Take the bathroom vanities. We eliminated the use of vanity basins entirely by taking the vanity surface and tilting it slightly to drain at the rear; this surface is our basin. We identified Trespa Meteon, a solid 70 per cent timber/30 per cent resin material, to do this. Its an exterior grade material that is totally waterproof, can be sanded if marked, is incredibly hard wearing, and at the end of life we have used it in largish sheets which, having a high value, we hope will be reused/recycled. Unlike laminated covered particleboard which goes straight to landfill, and can chip and crack.

Meteor is more expensive than laminated particleboard, but we are hoping to offset this by reduced labour and the fact we have eliminated the basin and the splashback – our mirror is both mirror and splashback combined.

This design philosophy was taken throughout the fit-out: use as few materials as possible. Fix them mechanically to allow demounting and disassembly; reuse and recycling; use high quality and high-durability materials; ask if a surface, such as plasterboard, is really necessary – in many instances we have done away with plasterboard lining by careful detailing and attention to detail – and the use of an access floor through which we can run all our services. The end result we think will be a clean and sophisticated aesthetic in the spirit of less is more. It requires more thought at the design stage, but well worth it.”

Table 5 highlights the key issues and products used in the fit-out of CH₂

Item/ Location	Material, Supplier	Comment
FLOORING		
Kitchenette floors	Marmoleum. Forbo Nairn.	
Shower walls and base	Cork. Comcork low-profile.	
Office floors	Final decision not made at time of writing.	An extensive R&D task was carried out on carpet, narrowing the field to Ontera and Interface modular products.
Ground floor except retail	Bluestone. Signorino Tile Gallery.	
Tiles to winter and summer terraces	Precast concrete paving tile, class II finish. SA Precast; Unicrete; Fabcon	High-recycled content concrete used. Precaster uses excess concrete to make pavers.
Exposed roof concrete surfaces	Sealed concrete with Parbury Emerproof – WB reinforced liquid applied membrane.	
Mezzanine	Strip timber flooring. Kennedys/Nullabor.	Post-consumer recycled timber.
Bathrooms	Synthetic rubber. Kinetics Flooring Australia.	
CEILING		
Off-form precast concrete panel	Painted concrete. S.A. Precast.	
East core toilets	Suspended metal ceiling system, supplier TBC. Hunter Douglas/Luxalon	
Solid panel – internal cladding to some toilet walls; some highlight walls to ground floor entry foyer	Phenolic resin/ wood fibre composite laminate. Trespa Athlon.	
Solid panel	Phenolic resin/ wood fibre composite laminate. Trespa Athlon.	
Solid panel	Phenolic resin/ wood fibre composite laminate. Trespa 13mm skirting panel.	

Table 5 Fit-out Key ESD Materials Schedule.

Item/ Location	Material, Supplier	Comment
WALLS		
Generally	Exposed off-form concrete (refer base building).	
Internal lining to window surrounds	Gypsum plasterboard. <i>Boral</i> .	
GLAZING		
Clear single glazed	Glass. G James/DMS/Pilkington.	
PAINT		
Powder coats	Powder coat finish. Dulux.	
General purpose	Low VOC, low-tint acrylic paint. Dulux Natural white low sheen acrylic, Natural white flat acrylic, Natural white semi & high gloss, Obsidian glass low sheen.	
General purpose	Enamel paint. Dulux.	
MISCELLANEOUS		
Vanity benches/ basins	Phenolic resin/wood fibre composite laminate. Trespa Meteon.	Refer to the preamble on the Fit-out section.
Plywood to some partitions, shelving, doors	Plantation softwood hoop pine. Brimswood	
Vanity 'blade' bathroom vanities	Phenolic resin/ wood fibre composite laminate. Trespa Meteon.	

Table 5 Fit-out Key ESD Materials Schedule.

Workstations, Loose Fittings and Furnishings

At the time of writing this paper, tenders were being let for workstations and loose fittings and furnishings. As such, it is not possible to identify these here. The design team did, however, identify the following items would receive preference in the tender considerations from an ESD perspective:

- volatile emissions;
- embodied energy; and
- recycled content.

Case Study: Concrete at CH₂

Concrete is a ubiquitous material in construction, offering strength, versatility, and durability at a relatively cost effective price.

Concrete is also highly energy and greenhouse gas intensive. The production of one tonne of concrete typically uses cement with an associated environmental price of one tonne of CO₂. Figure 2 below illustrates the emissions impacts of a tonne of concrete made using entirely Ordinary Portland Cement (OPC) through to various fuel mixes and substitution of OPC with recycled extenders such as blast furnace slag and fly-ash.

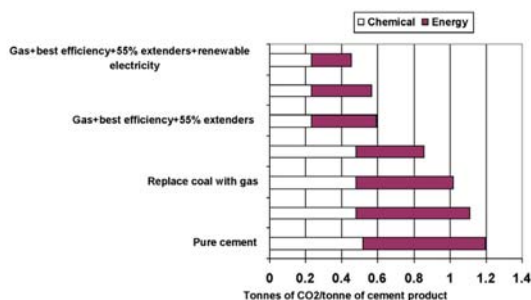


Figure 2: Chemical and energy CO₂ emissions from cement production under various conditions (Pears, 2000).

As Figure 2 illustrates, greater than 50 per cent reductions in emissions can be achieved by using gas-fired dry-process cement and recycled extender or 'supplementary' products. The total embodied energy of reinforced concrete can be further reduced by using post-consumer recycled steel reinforcing produced from an electric arc furnace (EAF) process, such as used by Smorgon Steel. While EAF mills are inherently up to 70 per cent more efficient than blast-furnace mills, they can only process existing steel ingot or recycled steel.

Concrete, due to its use in large quantities in many commercial buildings, is often a major contributor to a base building's overall embodied energy. While a detailed life cycle analysis (LCA) or embodied energy analysis of CH₂ has not been undertaken, the 2000 Melbourne 'Build LCA' study looked in detail at a range of buildings, including two small offices (6,500m² and 27,350m² respectively) as well as other building types. The results by material for these buildings, Office 1 and 2 respectively, are provided in Figures 3 and 4 below.

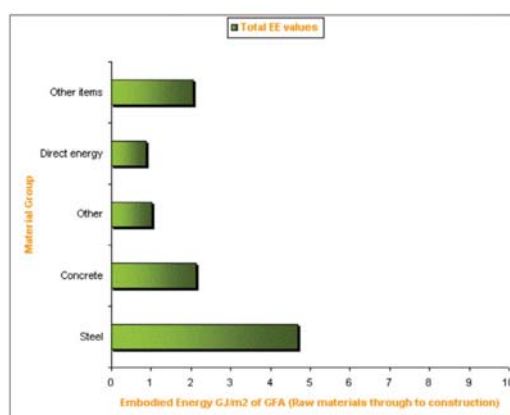


Figure 3: Small Office 1 Embodied Energy (Input/Output type analysis) 6,500m² GFA (Greening the Building Life Cycle 2000).

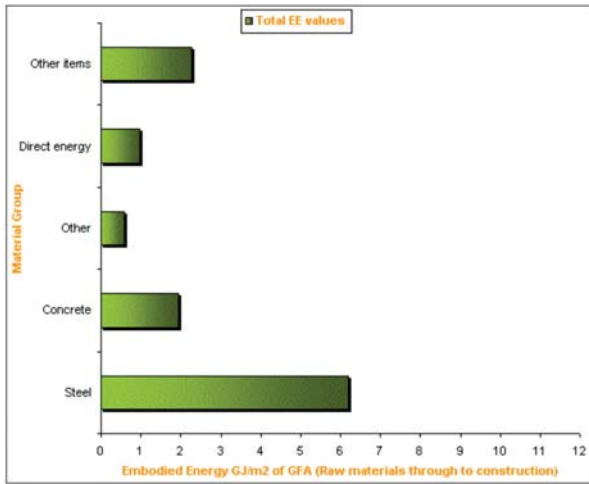


Figure 4: Small Office 2 Embodied Energy (Input/Output type analysis) 27,350m²GFA (Greening the Building Life Cycle 2000).

As Figures 3 and 4 illustrate, concrete was found to be the second largest single energy input into the buildings, at 2.0 and 2.2GJ/m² respectively. This represents approximately 20 per cent of their total embodied energy. At 12,500m² gross floor area, CH₂ contains approximately 5,200 tonnes of concrete (not including mass of steel reinforcement).

On the basis of a business-as-usual worst case this equates to approximately 5,200 tonnes of CO₂ – in broad numbers equivalent to the emissions of 12,500 family cars travelling the Australian average of 15,000 km each over a year.

The CH₂ design team was looking to reduce embodied energy as much as possible. However the project's stated intention to achieve six stars under Green Star meant every credit point mattered. The team now had, through the credits, an implicit energy 'budget' to attain.

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Title	Aim	Credit Criteria Summary	Credits available
Recycled Content of Structural Concrete	To reduce embodied energy and resource depletion due to use of concrete.	Up to three credits are awarded where concrete used in the building construction or refurbishment has a significant recycled content: <ul style="list-style-type: none"> • One credit is awarded for aggregate replacement in 75% of all concrete by volume as follows: one credit = 30% of aggregate is recycled concrete aggregate (or equivalent) • Up to one credits for awarded for use of supplementary cementitious materials in 75% of all concrete by volume as follows: 1 credit = 30% of cement is replaced with industrial waste product; two credits = 60% of cement is replaced with industrial waste product (for precast concrete the % of cement replacement is reduced to 20% for one credit and 40% for two credits). If no new concrete is used in the refurbishment of an existing building type 'not applicable' in the credits achieved column.	Three

Table 6 Green Star – Office Design (v1) credits regarding concrete (Green Building Council Australia, 2004).

Although the pioneer Melbourne green commercial office building '60L' (also with Hansen Yuncken as the contractor) had achieved up to 60 per cent replacement of Ordinary Portland Cement (OPC), this was in a low-rise refurbishment project, not in a new build high rise project like CH₂. Furthermore, while the Green Star credits for pre-cast concrete were theoretically achievable, they were untested in the field.

CH₂ presented a number of challenges:

- the building stands 10 storeys high and requires high-strength floor slabs and columns developing up to 80MPa;
- 32 per cent of the total quantity of concrete used is precast, including many curved concrete ceiling panels requiring a very high class of visual finish;

- the project is driven by tight commercial realities. There is little provision to delay stripping of concrete to allow the use of later strength-developing high-extender mixes. This would also prove a challenge with regard to managing shrinkage and cracking.

Despite these challenges, CH₂ was keen to achieve three credits for recycled content of structural concrete. A strategy was developed to measure and document how credits were being met. This strategy, which evolved through tender and post-tender discussions between the builder, the City of Melbourne and the architects, took the following form:

- develop a complete matrix of concrete elements to be used in the project which addressed for each element the percentage of total concrete, the number of days at which requisite strength would be developed, and so forth;

- ii) dynamically identify stretch targets and problem areas in pre-construction stage;
- iii) undertake in-depth builder-architect workshops to establish what may be possible;
- iv) testing, research and development by concrete contractors to establish parameters.

To view the complete versions of the concrete matrix see www.ch2.com.au. Tables 7a and 7b show the basic features of the concrete elements measured.

Element	Mix designation	Comment/risk	Strength	Drying shrinkage	Opportunities for reduction	Cement replacement %	Aggregate replacement %	Slump	Plasticiser	Qty	Supplier

Table 7a Summary of input to concrete Matrix.

	Qty m ³	% of concrete on job	Aggregate replacement (repl)	% of project cement repl	Cement mat repl	% of proj agg repl
Totals	7262	100%	62.90%	37.24%	86.15%	54.96%
Green Star – Office Design Criteria and compliance notes.			Needs to be >75%	Needs to be >30%	Needs to be >75%	Needs to be >30%

Table 7b Outcome of concrete Matrix.

One early outcome of this process was an application by Boral to the Green Building Council for an exemption to enable washed aggregate (aggregate washed out of un-used concrete returned from CH₂ or other projects) to qualify as ‘recycled’ aggregate under the credit. This exemption was granted. While the amount of this aggregate only accounts for one to two per cent of the aggregate used in the project, it proved crucial in assisting it to achieve the levels set.

Boral agreed to the targets identified in the matrix but it was new territory for the company. Boral had a unique commercial advantage in the project as three of its city plants had facilities to crush recycled concrete – critical to the project reaching recycled aggregate targets. Boral was unwilling to use genuine post-consumer recycled aggregate (such as that available from their venture partner Delta or Alex Fraser) in most high-strength applications due to concerns about the effects of residual cement on binding strength, shrinkage and other technical performance characteristics.

The process raised several subtleties not reflected in the Green Star credits. Not least of these were that the supplementaries locally available in each state in Australia have quite different performance characteristics. One very positive outcome of the project was an agreement reached with Boral to share some aspects of the concrete’s characteristics in the public domain. This data was forwarded to the Green Building Council to assist with the refinement of the rating tools.

Even so, construction was not without challenges:

- Significant cracking was encountered with one major floor slab. While this was found not to affect structural integrity or aesthetics (it was hidden under the access floor) it required further refinement by Boral to address the problem.
- The physical characteristics of the mix resulted in different flow patterns and mix behaviour in pouring the curved pre-cast concrete panels including scalloping, bubbling and colour variation – all highly problematic in this high visibility feature. This was only resolved through significant experimentation and development, costs for which were born by the City of Melbourne CH₂ project budget and represent part of the normal costs associated with the design and construction of a building.

Environmental Benefits of Concrete Specification

Detailed analysis of the embodied energy savings achieved at CH₂ have not been undertaken. Without this it is difficult to establish total savings, particularly as there are indications that concrete contractors increased the quantity of Ordinary Portland Cement (OPC) in the mix to achieve strength and performance, in addition to the requisite levels of supplementaries. However, it is likely significant savings were achieved and the project contributed to the body of knowledge in this area. It is estimated these savings were between 20 and 30 per cent of potential embodied energy, equivalent to taking 250 to 375 cars off the road for one year (calculation based on the concrete schedule and percentages saved).

Environmental Benefits

Quantifiable Environmental Benefits

There is no doubt the exhaustive specification process for CH₂ has reduced the environmental burden associated with its construction. The example of concrete alone indicates a significant greenhouse gas saving. Other key examples of likely benefits include:

- minimal use of rainforest and high-conservation value forests for much of the timber construction, through using recycled timbers;
- reduced embodied energy from the use of 100 per cent post-consumer recycled content steel for reinforcement;
- design for reduced materials use, flexibility and demountability in the fit-out. In addition to savings in capital construction, this is likely to result in compound savings through avoided consumption and waste during churn;
- savings for the project-wide emphasis on specification for the 100 year life-cycle costing model, with its emphasis on durability.

Accurate quantification of the environmental savings and avoided impacts will only be possible when an audit has been undertaken. This is likely to be the subject of future research.

Supply Chain Transformation

CH₂ has already had a dramatic impact on the broader building materials supply chain through its iconic status, profile, and significance as a groundbreaking public sector building. Examples of this include:

- the development of new products specifically for the project (e.g. the shower towers, precast and in-situ concrete mixes);
- placing pressure on manufacturers and suppliers to think about, and gather data on, the environmental performance and characteristics of their products.

Contract Development

A key area of concern and barrier for many projects breaking new ground is managing risk. There are a number of areas in which CH₂ has re-thought contractual arrangements to allocate, share or manage new risks with regard to materials. These include:

- developing the Environmental Performance Questionnaire-approved approach and the proposed Bank Guarantee to minimise risk of undesirable product substitution on-site.

Illustration of 9 Challenges, Complexities and Barriers

One of the greatest contributions of CH₂ to ESD will no doubt be identifying challenges, complexities and barriers in green building design and construction. These include:

- the challenge of maintaining quality control in areas of new product development (refer 'Lessons learned');

- identifying environmentally preferable products. Regardless of the complexity of product assessment processes, no team has access to perfect information. Subsequent concerns of environment groups illustrated the challenges of design teams and their consultants being sustainability experts across a literal planetary range of products;
- negotiating solutions to unforeseeable situations arising from the use of novel materials (e.g. concrete) with contractual parties in the framework of traditionally adversarial and risk-averse contractual relationships.

Explicit Diffusion, Communication and Education

The City of Melbourne has embarked on a comprehensive knowledge diffusion program, including the production of this case study. Lectures, seminars, conferences, books, articles in the trade press and broader media have all contributed to lifting awareness of the CH₂ project, its ESD ambitions, and what it aims to achieve. As the project moves toward completion, the focus is on providing articles for architectural magazines that designers and clients read. CH₂ will be researched and documented in additional case studies. This broad communication agenda ensures many of the lessons and achievements of CH₂ will be adopted by other projects.

While the extensive database of 'scored' products remains the intellectual property of DesignInc, the City of Melbourne is exploring ways to make at least some of this knowledge available to a broader audience. In the meantime, this knowledge provides an important resource that will enable architects to leverage off the experience of CH₂ to pursue eco-preferable products in other public and private sector projects, and to set a benchmark for other firms to meet and surpass.

Participation in the development of CH₂ has stretched and educated all those involved. A major outcome of the project will be increasing the knowledge and experience of architects, engineering and cost-planning consultants, builders and subcontractors.

Lessons Learned

Perhaps as significant as the 'iconic' achievements of CH₂ are the myriad of small changes in approach that may not be documented. One example of this, observed by Bertoni, is the changing attitude to waste on-site:

"Once you start seriously dealing with ESD design it is not just quality and aesthetics driven on conventional lines. I don't think we have wasted anything, we have repaired it instead. If a precast slab turns up that is not quite right we don't send it back. It represents a significant resource and energy investment. Instead we ask how we can resolve an apparent problem."⁹

⁹ Interview with Claude Bertoni, DesignInc 24/01/2005.

This raises real challenges for the architect or project supervisor. Building contracts and Australian Standards have evolved over time to allow tight control over the quality, cost and extent of projects: but what happens where no contractual experience or Australian Standard exists? The use of high-supplementary mix concretes on CH₂ is a case in point. The end result, as discussed in the case study, is finishes that do not meet any established Standard, although their qualities specified by the architect and client are achieved.

How does the architect hold the builder to account? How does the supervisor prevent a reduction in perceived quality? The only answer to this appears to be more hands-on time, in the concrete yard, in the joinery shop, as indeed things were done 20 years ago. As Bertoni says, “ESD has generated a new generation of products which are simply not well understood. There is a learning curve for what they can and can’t do, and the project simply has to allow more time up-front with the builder to make sure things are done right¹⁰.”

A high profile issue that arose on the CH₂ project was the selection of timber for the main façade windows. The contract specification for the project identified two categories from which timber elements could be constructed – recycled hardwood and regrowth hardwood (Mountain Ash). Recycled timber for this project was defined as:

- Being previously processed;
- Not being from milling or remnant dead native forest trees;
- Not being chemically impregnated or contaminated;
- Not being less than 10 years unused since prior usage;
- Not being from any form of land clearing; and
- Not being salvaged from Forestry Operations.

Timber for regrowth hardwood elements were specified to be from a source a minimum 10 years old, obtained from sustainably managed, native timber, private or State forest areas approved by the Victorian Department of Sustainability and Environment for selective logging or regrowth timber. The specification also noted that logging of original growth timber would not be acceptable. Verification required as part of the contract specifications consisted of audited proof by way of the Forestry Authority’s approval to log, age and drying certifications, order receipts, transport delivery dockets. Conservation groups, however, pointed out during construction that the timber was not independently certified. They contended that Victorian Government forestry practices were unsustainable.

This proved to be a difficult issue to resolve, with strong and divergent opinions from different stakeholders. In the end, the project team maintained the original contract specification on the basis that it was a living example of the learning curve required in such projects, and on the basis that the supplier guaranteed it was regrowth rather than old-growth timber. This assisted with meeting cost and project timeline constraints. It was also decided the project would seek to use Forest Stewardship Certified (independently certified timber for environmentally preferable management) Victorian Ash from south-eastern Victoria.

Other lessons learned include:

- The importance of targets. Green Star does make a difference. It is extremely unlikely that opportunities as profoundly difficult or potentially risky as the concrete innovations would have been undertaken without the Green Star credit incentive.
- Setting new standards and breaking new ground has a price. DesignInc estimates the additional ESD materials research cost the firm between \$50,000 and \$70,000. This cost is considered an investment by DesignInc, as it expects to reduce the cost of delivering ESD projects in future and will provide a competitive advantage when tendering.
- If a consultant or other party invests in new knowledge, the contractual lines surrounding it can be blurred: who owns the resulting knowledge?
- A critical shortcoming in ESD product assessment remains third-party accredited standards for products and materials to confer confidence to design teams that a product is what it says it is.
- A holistic design philosophy can deliver cost savings, project benefits and solutions that using conventional approaches would not deliver.
- Some things were better to cost with a supplier on hand who could assist with detailing. Where this has been done at CH₂ it has invariably assisted keeping costs down and achieving the design objective.

Conclusion

Green building is at a point where there is still a lot of learning for all involved. Each new project contributes to this knowledge and brings benefits to the environment and community. The CH₂ project demonstrates the importance of continued education of architects, the construction industry and the product manufacturing industry. This paper has demonstrated the challenges and opportunities of integrating environmentally responsible materials into a building project. Opportunities exist in selecting materials that have low impacts in their manufacture and use, as well as longevity in their aesthetics and inherent qualities, such as strength and recyclability.

¹⁰ Ibid.

Appendix 1: Acronyms

BedZED	Beddington Zero Energy Development
BEES	Building for Environmental and Economic Sustainability
BRE	British Research Establishment
CH ₂	Council House 2
CSIRO	Commonwealth Scientific, Innovation and Research Organisation
EPDS	Environmental Performance Data Sheet
EPQ	Environmental Performance Questionnaire
ESD	Ecologically Sustainable Development
HDPE	High Density Polyethylene
LCA	Life Cycle Analysis
LEED	Leadership in Energy and Environmental Design
MIPS	Material Intensity Per Service Unit
MPa	Mega (million) Pascal unit – measure of material's tensile strength
OECD	Organisation for Economic Cooperation and Development
OPC	Ordinary Portland Cement
PVC	Polyvinyl chloride
QS	Quantity Surveyor
SCS	Scientific Certification Systems
VOC	Volatile Organic Compound

Appendix 2: Glossary of Terms

Churn

Amount of turn over: in this case used in conjunction with churn energy as distinct from operational energy. Churn is the number of participants who discontinue their use of a service divided by the average number of total participants. Churn rate provides insight into the growth or decline of use as well as the average length of participation in the service.

Eco Footprinting or Footprinting

A method of measuring the impact of certain activities and lifestyles on the planet – total land used to produce a product. The results of the calculations are given in how many planets it would need to maintain the activity or lifestyle. It is a way of depicting resource consumption.

Embodied Energy

Looks at the total non-renewable energy used to create a product or material from cradle to cradle.

Heat load

Amount of heat needed to be mitigated by a cooling system or extraction system.

Low e Coatings

Low e coatings refer to finishes which have a low emission of Volatile Organic Compounds (VOCs). They are usually water based products.

MIPS

The Material Intensity of a product or service is found by adding up the overall material input which humans move or extract to make that product or provide that service. It puts life cycle thinking at the beginning of the product chain. The MIPS is measured in kilogram per unit of service. The material input is calculated in five categories: abiotic raw materials, biotic raw materials, water, erosion and air.

Supplementary Cementitious Material

Includes materials such as fly ash, blast furnace slag and silica fume which are industrial waste by-products (also referred to as high extender content cement, recycled content cement). They can be added to the cement mixture to replace Ordinary Portland Cement, which is a raw product with a high embodied energy.

Recycled Aggregate

In concrete, aggregate takes up 60 to 80 per cent of the concrete mixture. The aggregate is normally granulated fragments of inert mineral materials, including sand, gravel, crushed stone, slag, rock dust, or powder. Recycled sources of aggregate can be reclaimed crushed concrete or masonry, or other industrial waste products which have the size, weight and durability characteristics needed, i.e. asphalt.

VOC/s

Volatile Organic Compounds which can be emitted from various internal fit-out materials such as paint, carpets, and condensed wood products. VOCs have been found to be detrimental to human health.

Appendix 3: DesignInc's Top Ten Lessons Learned for Specifying Preferable Materials

1. Be careful of greenwash.
2. There is no avoiding research – allow for time and resources to enable good decision making:
 - use existing tools, e.g. Ecospecifier, the Environment Design Guide, case studies, internet;
 - use contacts;
 - attend conferences to keep up to date;
 - develop an in-house assessment system/ checklist- check out the one page materials questionnaire on Ecospecifier as an example;
 - be patient with and communicate clearly with suppliers; and
 - work towards developing an in-house materials database and staff education strategies to learn from the process.
3. Bring materials to the front of the design process.
4. Rethink preconceived notions of material selection and application.
5. Design in solutions that minimise material consumption (e.g. Maximise natural/integrated, not applied finishes, therefore materials to be a natural backdrop to form, not a primary aesthetic).
6. Understand what you are specifying so you don't get caught out later:
 - cost and time implications – be prepared that some items may cost more due to availability, but demand will eventually bring prices down;
 - suitability of the product for the intended application.
7. Collaborate with local environmental groups – they can be a good source of information.
8. Be more amenable to variations in visual finish control to minimise material wastage through rejection:
 - develop a good relationship/ commentary with the builder to ensure project objectives and quality is delivered;
 - where options exist, choose a process that gives a good result with the least risk of material wastage;
 - where a more refined finish is required, limit it to smaller areas.
9. Be realistic about lifespan design considerations (e.g. if the design aims at flexibility or is faddish, then demountability, recyclability and reuse may be more important than long term durability).
10. Don't get lost in the enormity of the exercise – take it in small bites and don't feel the need to reinvent the wheel every time. Making a small improvement is better than none at all.

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