# Green Buildings - A Case Study Review of the Construction Process

## Ecological Sustainable Design

Clare Louise Newton, University of Melbourne, Australia
John Wilson, Swinburne University of Technology, Australia

*Abstract: The City of Melbourne in Australia is currently constructing one of the world's greenest buildings. Construction on the 10-storey building called Council House 2 (CH2) began in early 2004 with Council accepting a 20-25% cost premium for green initiatives in order to test outcomes and provide a leadership model for other developers. This paper documents the building process and describes key issues such as the procurement method, structural rationale, material selection, and onsite construction process and construction transport issues. The paper examines CH2 in relation to other Australian and overseas best practice within the ecological sustainable design(ESD)framework. CH2 is one of the first designs to use the new green star rating system. Introduced by the Green Building Council of Australia (GBCA), the green star rating system provides a systematic framework to quantify the degree to which ESD principles have been incorporated into the building design. CH2 has been given a six-star rating is therefore considered an international best practice model. CH2 has unusual design aspects and so a surprising finding is that the procurement and construction process of CH2is relatively conventional. This is contrasted with another recent green office building and it is argued that the green star rating system and specification is providing the builders with a more systematic basis for decision making on ESD issues.*

Keywords: Sustainable Construction, ESD, Green Star Construction Rating, Sustainable Material Selection, Integrated Design Teams

## Introduction

**THIS PAPER DOCUMENTS** the building process of the City of Melbourne's Council House 2 ($CH_2$, refer www.melbourne.vic.gov.au), as well as elements such as the project's major structural design, material selection, construction processes and transport issues. It examines $CH_2$ in relation to other Australian and overseas best practice within an ecologically sustainable design (ESD) framework. An assessment of the current state of related industries within Australia is included, and areas for improvement in meeting the needs of the expanding ESD industry are identified.

$CH_2$ was one of the first buildings in Australia to use the new Green Star rating system in its design process. Introduced in 2003 by the Green Building Council of Australia (GBCA, refer www.gbcaus.org), the Green Star rating system provides a systematic framework to quantify the degree to which ESD principles have been incorporated into a building design. The system helped the building contractors of $CH_2$ to identify and address key ESD issues in its construction, which resulted in a more pragmatic and faster decision making process.

This paper begins by discussing the key design features of the $CH_2$ building, followed by a description of the integrated design process and how this facilitated innovative structural and design decisions. Although there are many unusual design aspects within the $CH_2$ building, the procurement and construction process of $CH_2$ was relatively conventional. This contrasts with another recent green office building, 60L (refer www.60L.greenbuilding.com) constructed in Melbourne, and it is argued that the Green Star rating system and specification provides builders with a more systematic basis for decision making on ESD issues.

Issues relating to construction such as the structural rationale, the materials, the procurement method and the onsite construction practices are also described in this paper. By detailing these issues, readers can compare and contrast $CH_2$ with their own experiences of construction. While innovative in design, the key observation is that the construction process of $CH_2$ follows conventional practice.

INTERNATIONAL JOURNAL OF ENVIRONMENTAL, CULTURAL, ECONOMIC AND SOCIAL SUSTAINABILITY, VOLUME 2, NUMBER 4, 2006
http://www.Sustainability-Journal.com, ISSN 1832-2077

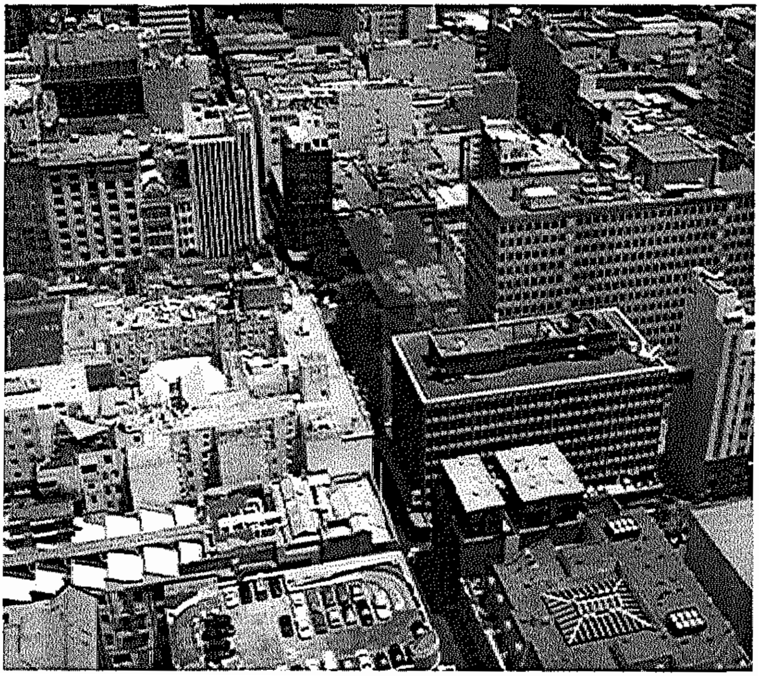
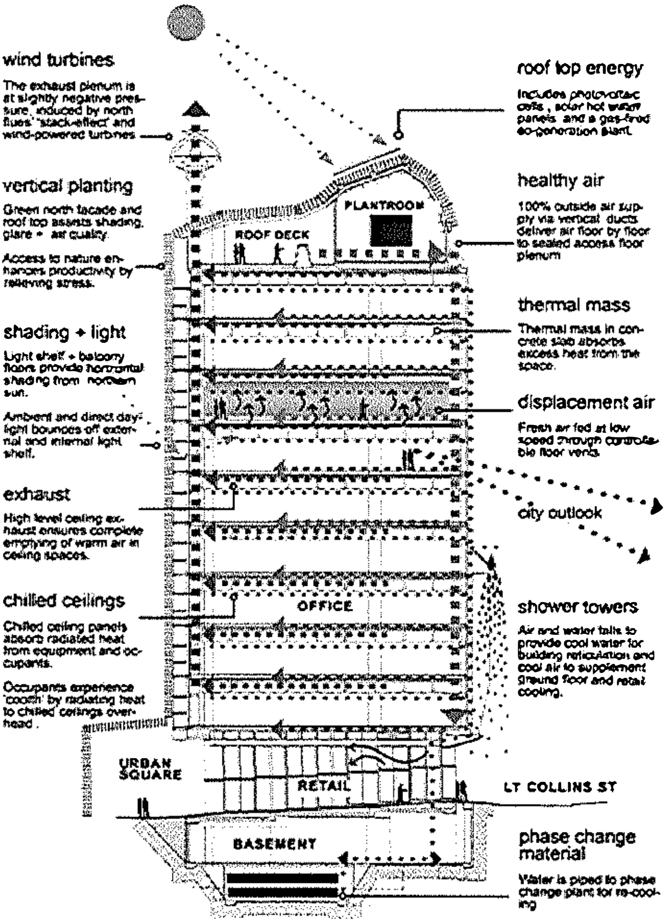


Figure 1: Red Highlights the Site for Council House Two

## The Design and the Structure

Hansen Yuncken began construction of the 10-storey, $51 million building for the City of Melbourne in early 2004. The construction site of 1,316 m² is only accessible from city laneways. The concrete structure is conventional in situ construction except for the use of precast sinusoidal concrete ceiling panels. Two rows of concrete columns are located at 8200 centres just inside the north and south facades with a further row of columns offset from the centre of the floor plate. The proportions of the site dictated a 'deep space' floor plate which presented design challenges in terms of lighting and air conditioning. The gently corrugated ceiling has resolved some difficulties arising from the 22m building depth by allowing for air distribution ducts yet enabling a maximum ceiling height so that light can penetrate deep into the offices. Car parking is provided at basement level. The car park is flat floored rather than ramped to allow it to be converted to other uses in the future.

Some of the design features of $CH_2$ include 100 per cent fresh air, chilled panels, night purging and storage of energy using phase change materials. The cooling, heating, ventilation and lighting systems, will largely be run using locally generated renewable energy. Consequently, the City of Melbourne expects to reduce its electricity consumption by 85 per cent, its mains water consumption by 72% and its gas consumption by 87 per cent. A gas-fired co-generation plant will provide about 40 per cent of the building's electricity but with lower carbon dioxide emissions. Waste heat from the cogeneration plant will be recycled to provide about 40 per cent of the air heating/cooling system.




**BIO CLIMATIC SECTION**

Figure 2: Section Sketch Showing how the Building Works

The key international precedent for $CH_2$ was a 1997 English building called 'The Environmental Building'. Constructed for the Building Research Establishment (BRE), this building was intended to demonstrate the latest innovations in energy efficient design that could be incorporated into office buildings. Like $CH_2$, it uses night cooling, thermal chimneys and a sinusoidal precast slab with in situ topping and ducts for ventilation and service supply. The sinusoidal floor works as a folded plate with the bottom curve typically in tension and the top in compression. An added advantage of the curve is that it increases the surface area of the thermal mass. Differences between the BRE building and $CH_2$ include the floor plate width. The BRE building has a shallow floor plan which helps cross ventilation (Thomas 1999).

## Integrated Design Teams

The conceptual design for $CH_2$ was developed by an integrated design team over a three-week period in January 2002. During this three-week charrette[1], the consultants were paid for their time on top of their tendered and accepted fees to complete the work. The charrette was useful for testing early ideas. For example, when the undulating ceiling was first proposed during the charrette the Quantity Surveyor was uncertain about the cost implications and so the structural engineer, Nat Bonacci, contacted precast concrete manufacturers and worked with them to obtain a costing. After the charrette the design continued to be developed by individual companies who were part of the integrated design team. The companies charged fixed fees over a 12 month period and held weekly meetings to coordinate and resolve issues.

It is useful to compare the $CH_2$ process with two recently completed green buildings in Melbourne. Green Building Partnerships (GBP), the developers of 60L, conducted a series of design workshops or charrettes over a period of four months to develop the design of the building and services. They established an integrated design team with all the critical players represented including the primary tenant. Following the design workshops, 10 months were spent researching, developing and writing the specifications. GBP provided a detailed and prescriptive green specification to ensure ESD principles were explicitly incorporated in the contract documents.

By contrast, the current trend is to use performance-based specifications to increase flexibility and encourage innovation in the construction phase. Design planning for a recent green building in Melbourne (National@Docklands) also involved collaboration but over a longer timeframe. The Design Review Group (DRG) conducted weekly meetings to coordinate and resolve issues over 18 months involving 10 to 25 people including the tenant, the architect, the owner, the builder, and the workplace designer.

The design process of commercial buildings is complex and collaboration between a range of consultants is essential. Yet intense collaboration so early in the design process as occurred in $CH_2$ is more unusual. The collaborative process for $CH_2$ enabled innovative decisions to be made with a degree of certainty in terms of constructability and cost. Most publications outlining recent international exemplars of sustainable architecture do not mention the importance of the architect working collaboratively with the client and consultants at an early design stage. One notable exception is Kibert (Kibert 2005) who includes the charrette as an emerging tool and provides guidelines for the successful integration of a high performing team.

---

[1] The French term 'charrette' originated in the Ecole des Beaux Arts in the 19 th century. Architecture and art students worked frantically in the studios to complete their work as before the cart or 'charrette' was circulated to collect the final drawings

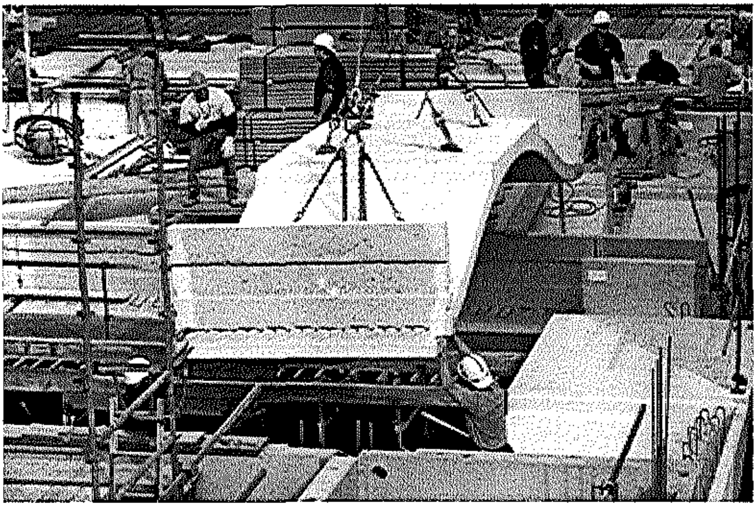


Figure 3: On-site Insertion of a Precast Concrete Curved Beam

## Contract Types and Organisational Structures for Project Delivery

The type of construction contract selected for the delivery of a project has a significant impact on the success of developing and implementing a green design. More time is needed at the design stage to fully integrate ESD design features, and this must be reflected in the type of project contract selected. Innovative green technologies using less common materials and methods are more difficult to document in advance of tendering for a traditional contract. Best practice depends on where products are sourced from, transport costs and manufacturing methods.

A traditional construction tender based on detailed design documentation, a 'novation' contract or an 'alliance' contract could all be successfully used for the delivery of green commercial buildings, if sufficient time is invested at the conceptual design stage. However, it is unlikely that a 'design and construct' contract, or a 'private public partnership' (PPP) would successfully deliver a green commercial building due to the design being locked in at an early stage with less flexibility to fully develop and integrate green initiatives. This situation may change as the green commercial building market becomes more mainstream and mature (Wilson 2006).

In a true alliance partnership, all the parties involved have collective responsibility for delivering the project. Under an alliance arrangement, non-owner participants are paid on an 'open-book compensation model', in which direct costs and project-specific overheads are reimbursed based on audited actual costs. The alliance partners also share in the profit and loss depending on how actual project outcomes compare with the pre-agreed targets (Ross 2003).

Alliance contracts in other sectors have been found to dramatically improve innovation, troubleshooting and significantly reduce litigation. They have also been shown to reduce costs and timelines, as all parties have a responsibility and incentive to make the project succeed and, conversely, share the pain if things go wrong. Many experts suggest green buildings are natural candidates for alliances due to the importance of innovation and new work practices that are needed for them to succeed.

Alliances are a relatively new form of construction contract within Australia and this may have been one of the reasons why the City of Melbourne preferred to negotiate a more traditional procurement process. The contracts for the $CH_2$ project were conventional with a tender for construction based on a detailed design, documentation, green specification and guaranteed Bill of Quantities offered to a short-list of building contractors.

Hansen Yuncken was the successful tenderer and entered into a contract with the City of Melbourne based on a modified version of AS2124 with a Council representative appointed as the superintendent for the project. Hansen Yuncken came to the project with expertise from 60L, a smaller green office building constructed for the Green Building Partnership. In contrast with 60L, the construction process of $CH_2$ is relatively conventional. During the construction of 60L, significant emphasis on ESD issues was placed on every construction task, sometimes at the expense of budget and program. As a result, the construction process and relationship between the client and the building contractor was more complex. One possible reason why the construction of $CH_2$ has been more conventional is due to the newly developed green star rating system, which provides builders with a systematic basis for decision making on ESD issues. Thanks to the green star framework it has not been necessary for every decision to be argued within an environmental framework providing the green star ratings were not being compromised.

Hansen Yuncken also entered into a 'partnering arrangement' with the City of Melbourne, the design team, subcontractors and unions. The aim of the partnering arrangement was to foster a more consultative and collaborative relationship between all players where issues could be identified and solved in an expedient, collaborative manner. The partnering agreement does not have the profit and loss sharing components found within an alliance agreement. Its primary purpose is to remind all participants of the joint ambitions and good will of the project.

As a government body, the City of Melbourne needed to be confident that risks were controlled. The $CH_2$ Project Superintendent ensured the initial budget was realistic and the Quantity Surveyor guaranteed the final building costs would come within five per cent of the original budget. The builder signed off the documentation before contracts were let to say the building would be fit for constuction (Hes 2004).

As a risk management strategy, the builder let out as many contracts as possible early in the process. Hansen Yuncken only employs a small core team of staff on an ongoing basis so they always aim to confirm sub-contracts as early as possible. This has enabled Hansen Yuncken to seek the most suitable subcontractors for the work. Hansen Yuncken has eight staff in the site office including three foremen. Two carpenters and eight labourers employed by Hansen Yuncken work with various subcontractors. Currently around 70 workers are employed onsite during the week. This numberhas doubled in the last 12 months.

There is an unusual relationship between the $CH_2$ builder and the client/developer. In most construction projects a project manager or architect would normally take on the role of independent arbiter between the client and the builder. For $CH_2$ the superintendent is a client employee. For this reason the site manager was initially concerned that decisions by the superintendent would not be independent. However, possibly due to the goodwill developed as part of project, the mistrust that traditionally exists between client and builder has been replaced with a collaborative partnership where requests for information (RFIs) from the builder have been quickly resolved. The site manager commented that RFIs have been more effectively dealt with for $CH_2$ than any other project with which he has had involvement.

## Design Documentation

It is difficult to fully document a green building if new technologies are being incorporated and/or if unusual materials are being sourced. The structure of $CH_2$ was fully documented when the project went to tender but some aspects are still being finalised during construction.

For example, the building's automated and adjustable western shutters are being designed within a provisional budget of $1.8 million. Signage, roof landscaping, lighting, installation of the phase change materials, fit-out of the lift car and the wind turbines were also included as provisional sums within the original tender documents.

A performance specification was provided for the windows and the builder offered a fixed price for these in the tender. Hansen Yuncken then took over the role of sourcing the supplier and providing prototypes for wind tunnel testing. They only could find one window manufacturer in Australia who would attempt to make the windows. Normally city buildings use aluminium window suites but re-growth hardwood was specified for $CH_2$. The builder employed a façade consultant to help with the design and testing of the facade.

During design development, the documentation system involved a File Transfer Protocol (FTP) site where all consultants involved uploaded and downloaded the latest drawings and specifications. Each consultant was responsible for uploading their latest drawings on Friday afternoons, at whatever stage of completion they were at, so that all members of the integrated design team could access and download drawings on Monday morning. Consultants were also responsible for ensuring their designs were consistent with other discipline areas so that an integrated design was achieved in a timely and informed manner with maximum coordination.

A prototype space was developed from which part of the project team started working. Elements of the design continued to be tested and developed within the early stages of the construction process. For example, chilled beams and ceiling panels, while not unknown in Australia, are relatively untested. The ceiling panels were redesigned through several prototypes to ensure they were effective and compatible aesthetically with the curved ceiling. The original mock-up was a flat panel but this gradually evolved into a curved panel with expressed pipes.

## Material Selection

The choice of construction materials is one of the key determinants of the environmental performance of buildings in terms of embodied energy, greenhouse gas emissions and toxicity. Desirable material features include:

- reused and recycled materials;
- materials with zero or low harmful emissions and toxicity;
- materials with high recycle potential, durability and longevity;
- materials that require less maintenance and have lower replacement costs over the life of the building; and
- materials that have greater flexibility under changing design requirements over the life of the building.

Life cycle analysis (LCA) of materials is required to provide a 'cradle to grave' inventory and impact assessment of the materials and systems. Embodied energy studies are needed to assess the energy used by a material in its production including mining, manufacture, transport, installation, maintenance, and finally demolition and recycling. This is a complex and developing field.

Research into the ecology of building materials, such as those by Berge (Berge 2000) and Lawson (Lawson 1996), attempt to itemise the energy and environmental impact of building materials, manufacture and construction. The major structural materials of concrete and recycled steel are listed by Berge as being durable, with readily available reserves and relatively low primary energy and water consumption in the manufacture. New analysis tools on the market such as 'Ecospecifier' (refer www.ecospecifier.org) are providing guidance on the environmental impact of commonly available building products. EcoSpecifier is a commercial database of building products that have been independently vetted against sustainability criteria. A similar tool is the US Greenbuild database that also rates the environmental performance of building products.

Green buildings materials are gradually becoming available but are not yet sufficient to make quick and informed decisions. For $CH_2$ design phase interviews were held with clients, consultants and builders, asking them to nominate areas where they found there was a lack of information. All of those interviewed mentioned materials selection as an area where there was limited information. One of the major problems was how to compare various options such as wool carpet versus nylon carpet (Hes 2004).

The CSIRO developed a method to help with the selection of materials in $CH_2$. It was a hybrid between a system of Environmental Performance Data Sheets (EPDS) developed by RMIT and an expert panel (Hes 2004). An EPDS was a detailed questionnaire sent to all product and material suppliers with the aim of completing a life cycle assessment. Many manufacturers or suppliers were unable to answer all of the questions but expert opinion was used to make informed decisions on the basis of the information supplied.

Pre-planning techniques were employed on the project to avoid unnecessary delays in approving ESD materials. For example, early in the contract, a number of low VOC caulking and surface finishing products were identified and approved for use throughout the project. Significant material selection was completed during the design stage and consisted primarily of traditional materials such as steel, reinforced concrete, glass and timber windows with very few additional materials used in the structure and façade construction. A review of material selection issues associated with the construction of other green buildings indicated some compromise was required during construction, either due to unacceptably high costs or availability and timely supply issues.

Builders face a dilemma when considering overseas materials against local materials. Often the overseas product is less expensive than the local product but there is no easy way to include the cost of extra embodied energy resulting from long distance transport. A further issue faced by builders is that some local products do not meet required ESD specifications.

A balance must be met between the environmental credentials of the material with its physical performance. Some materials that have low environmental impact (such as low embodied energy or toxicity levels) do not necessarily have good strength, performance or durability characteristics, which could result in a shorter life and higher maintenance implications. For example, the use of 60 per cent cement replacement, or the use of recycled aggregate in the production of concrete, raises some long-term strength and durability issues.

The $CH_2$ site manager points to another difficulty when using recycled materials. At present Australian standards and building regulations assume new materials are used in construction so that recycled products sometimes need to be tested to show they meet required standards, and this can slow the approval process.

The $CH_2$ for key materials are described below within the Australian context.

### PVC

In $CH_2$, PVC was only used for the stormwater in the basement. High Density Polyethylene (HDPE) a new greener plaster was typically used as a substitute product for PVC conduits and cabling with significant cost implications as there was only one supplier. In addition, the need to heat weld the joins was more labour intensive than using PVC adhesive. Green products like HDPE are likely to become more affordable as usage and competition increases and PVC is slowly phased out of the market.

In comparison, the 60L building specification originally banned the use of PVC but subsequent reviews and calculations revealed that a 100 per cent substitution of PVC would at least double the cost and have significant implications for some products which contained PVC components. As a compromise, PVC was eliminated from all water and wastewater pipes, electrical conduits and light fittings which resulted in a 50 per cent reduction in the use of PVC in the 60L building compared with a typical commercial building of the same size and use.

### Steel

In $CH_2$, a minimum 60 per cent by weight of the structural steel and connections was required to be in recycled steel and all reinforcement steel was specified to be at least 95 per cent recycled steel. Australian manufacturer BHP does recycle steel but was unable to provide a fixed percentage. As such steel was sourced from overseas where it was only available in limited sections and was not the same quality as the local steel. In the construction of $CH_2$, recycled structural steel was sourced from Thailand to satisfy cost and timely availability issue, but surprisingly the issue of additional energy consumption in transporting the material, which would be evident in a life cycle analysis, appears to have been ignored.

Australia has a relatively immature market for recycled building products and this can result in delays in the sourcing and supply of products and encourage contractors to purchase new products where the price and availability are guaranteed. This barrier will be overcome as the recycled market supply chain develops, matures and becomes more dependable such as recycled reinforcement steel which is readily available from a local manufacturer at competitive prices (Wilson 2006).

### Concrete

The aim in $CH_2$ was for 30 per cent of the aggregate to be recycled and 30 per cent of the cement to be replaced with industrial waste such as flyash or blast furnace slag. A green concrete mix consisting of recycled water, recycled aggregate and 40 per cent cement replacement with flyash resulted in a very low slump concrete that was difficult to place on site and did not achieve the durable performance and surface finishes required. As a compromise, green concrete was used for the foundation and basement substructure where approximately 60 percent of the concrete volume was required, and was easily placed and compacted. Whereas a standard concrete mix with better workability characteristics was used for the superstructure floor and column system.

The unique curved concrete ceiling panels were also manufactured off site with steel forms and a standard concrete mix with superplastieers applied to ensure a satisfactory surface finish. It took four months of trials before reaching a satisfactory concrete mix for the precast ceilings. The formwork for the curved ceilings is a totally sealed unit and so the concrete needed a high percentage of plasticers in order to achieve the correct flow without compromising strength.

Although it was not possible to use recycled aggregate in these forms as they are too unpredictable, Boral Green Mix was used for the in situ columns. Originally the team tried the mix with 40 per cent cement replacement with flyash but there were too many shrinkage cracks and consequently the quantity was reduced to 20 per cent. The experience of the recycled aggregate and flyash are reflected in other Australian and overseas examples where the desired surface finishes are difficult to achieve when using significant proportions of recycled aggregates or cement replacements.

### Timber

Timber use on $CH_2$ is to be recycled or from regrowth hardwood. Within the $CH_2$ documents, some materials were originally specified as products while others were required to meet a performance specification. The recycled timber used for the windows in $CH_2$ was easily sourced, however extra costs were associated with milling the well seasoned hardwood timber. The ESD varnish finish originally specified for the timber windows could only be guaranteed for three years and consequently was replaced with a standard acrylic paint product with a 10 year guarantee. Recycled and regrowth hardwood are readily available in Australia. Much public attention has been focussed on the use of renewable timber and Australia does have extensive sustainable timber available.

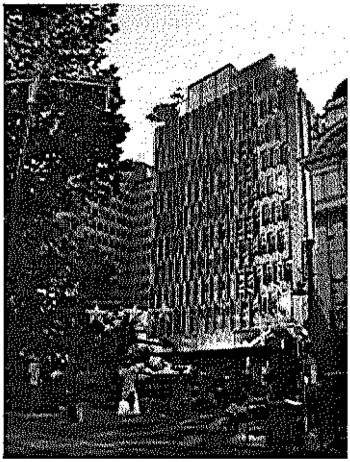


Figure 4: West Wall with Timber Shutters which Adjust Automatically with the movement of the Sun

## Site Practices and the Environmental Management Plan

The construction site provides great challenges to the successful implementation of sustainable building practices. In a separate study construction firms commented that the Australian construction industry is still driven by financial performance with success measured by cost, time and quality. In many cases, environmental performance is still regarded as a peripheral or secondary issue (Wilson 2006).

Tender documents for $CH_2$ required the contractor to provide and implement a comprehensive Environmental Management Plan (EMP) in accordance with the NSW Environmental Management System Guidelines. The EMP covered issues such as the construction impact on air quality, water supply and land quality. Under the EMP, the contractor is required to develop policies for reducing site waste, energy use, the selection and supply of materials and products and the re-use or recycling of salvaged products. Induction of all onsite staff is a mandatory part of the EMP. Good environmental and waste management, as required in the tender documents, achieves five points towards the Australian green star rating. In England, the comparable LEED rating system used for commercial buildings does not include points for the development of an EMP but does include points for construction waste management (Kibert 2005).

While Hansen Yuncken had an environment policy in place, their Environmental Management Plan was developed specifically for $CH_2$. Collex Waste Management Pty Ltd was nominated within the EMP document to manage the site waste disposal. The EMP is not limited to site activities but extends to issues of trade waste and energy use in the off-site trades. The monthly financial reports contain a section on environmental issues. Environmental audits of site practices are held at the start and the completion of the project, and at six-monthly intervals during construction.

A significant challenge for the building contractors is the continued management of large numbers of suppliers, subcontractors and tradespeople changing regularly during the construction phase. Onsite induction involving staff and subcontractors goes some way towards communicating the green intent of a project and the expected sustainable practices. For this reason, the union movement (which is a key player in the Australian building industry), needs to be engaged as a supporter of green buildings. Experience on site has demonstrated that some unions are actively involved in applying the principles of sustainability, while other unions and tradespeople were indifferent.

Surprisingly, the $CH_2$ construction site has been relatively straightforward. The builder is careful when selecting subcontractors and many have worked previously with Hansen Yuncken. There is also good will for the project within the various contractors, with larger firms keen to be involved as they consider green buildings and techniques will become increasingly important.

A key sustainability issue in the construction phase is waste recycling, or the management of residual material. Some project contracts specify that demolition and construction waste are to be separated into waste streams such as timber, concrete, steel, plaster and PVC. On previous sites, it was observed that the initial enthusiasm for separating the waste dissipated as the project progressed, and many recycling skips were found to contain a mix of materials. This type of behaviour may reflect ignorance, laziness or time pressures to complete a project and clean-up expediently. To ensure that sustainable practices are implemented onsite, the developers and building contractors often employ different strategies such as 'environmental policing'. This involves either the appointment of an officer dedicated to check practices, or random onsite visits by project managers. 'Soft' strategies are also applied such as involving union representatives in site meetings to reinforce the benefits to workers of sustainable practices.

A simple, alternative strategy used at $CH_2$ due to the tight space constraints of the site was to outsource the sorting and recycling of the residual material. Consequently, only one bin was provided at the site for waste and the waste contractor then sorted the residual material off site with a recycling success rate of around 80 per cent with the remaining 20 per cent committed to landfill. The cost of transport and sorting of waste was carried by the recycler and recouped through the sale of recyclable materials. The recycler provides a monthly report.

Site induction into waste procedures at $CH_2$ was therefore relatively straightforward. Building waste all goes into one bin while domestic waste is sorted in same way that it is done for most homeowners. Washout of concrete pumps is restricted to one area.

While waste recycling is tracked during construction, power usage has not been considered a key element in the overall energy savings possible. The site offices are within an existing City of Melbourne car park in which all lights are either on or off. Although not ideal, the cost to rewire was not considered efficient. To the builder's knowledge, power bills are no different from a normal site. Site water is not allowed to discharge into stormwater drains which is normal for all construction sites and water usage is not monitored.

The $CH_2$ building site is extremely compact with minimal space for storage of materials and cranage. Consequently, there is only one central crane and the contractor emphasises the use of precast concrete to minimise the number of people and trades onsite. The unique floor system, integral to the curved ceiling, required a change from the traditional construction processes of multi-storey buildings. The usual process is that services are fitted out to the lower levels whilst construction continues on the upper floors. In $CH_2$, the curved precast ceiling panels are being placed first followed by the in situ construction of the integrated floor beams. Services are then being fitted in the concave void above the precast ceiling before the in situ floor are placed spanning between the beams and enclosing the services. The resulting construction sequence is more complex and requires significant coordination between the different trades to achieve the integrated design in a timely manner.

The construction process is therefore slower than a normal city building of the same size. The limited site conditions and access, with just one crane, results in other logistical issues. In addition, the building has many unusual construction methods and is aesthetically complex requiring many trades to work concurrently. For example, the decision to include services within the floor voids means that trades like electrical, services and sprinklers work alongside each other rather than consecutively.

The work practices of the head contractor and the various subcontractors is very similar to conventional building construction, although one extra person has been employed to manage the environmental issues related to the project and document processes to ensure compliance with the green star rating system. Similarly, power and water usage and waste water treatment during $CH_2$ construction are considered to be similar to more conventional construction contracts. Major differences are associated with the façade systems and services such as heating, cooling, ventilation and lighting.

The Green Building Council of Australia may require an independent auditor to ensure the installation of services meets the green star requirements. Currently the construction process is largely self-audited by the builder and client. There is some uncertainty about the auditing process although there is goodwill to ensure the building is constructed in accordance with the requirements.

A key aspect of the green star rating system is the incorporation of green principles into the tender and contract documents. This is one of the key points made within 'A Green Vitruvius' which was written as a green architecture handbook (ACE 1999).

## Conclusion

$CH_2$ is a visionary world leading building in terms of ecological sustainable design with a 6 Star Rating in accordance with the Green Building Council of Australia rating system.

Given the innovative nature of the design and material selection, the construction process for $CH_2$ has been surprisingly conventional. The government client needed to manage financial risk and therefore a conventional tendering process was seen as important to bring certainty to the funding of the project. Traditional contract management often places the builder and client as adversaries with the architect or project manager acting as arbiter. Anecdotal evidence suggests the integrated team approach at $CH_2$ has not only helped facilitate the design stage but continued into the construction phase. In $CH_2$ it seems good will and collaboration between the team members has been extended to site workers and unions.

The $CH_2$ building contractor, Hansen Yuncken, had taken a key role in resolving some of the more unusual aspects of the building such as the use of recycled timber cladding. Difficult decisions in the selection and procurement of sustainable materials illustrate the extent of uncertainty that still exists in obtaining life-cycle data to help inform decisions. The material selection also indicated that a balance must be achieved between the environmental credentials (including transportation issues) and the physical performance of the material.

The construction of $CH_2$ has challenged traditional site practices and demonstrated the importance of developing and implementing an Environmental Management Plan to ensure standards are maintained during construction. The innovative mixed mode heating and ventilation systems incorporated in the building requires extensive commissioning and the client has allowed a 12 month period to optimise the systems to ensure performance is consistent with the design specification during the various seasons of the year.

## Acknowledgements

The authors acknowledge and thank Hansen Yuncken and the City of Melbourne for their input. The authors would also like to acknowledge Elizabeth Syndercombe for her comments and suggestions and the Masters students researching $CH_2$ as part of a post graduate subject 'Sustainable Buildings'. Illustrations have been sourced with permission from the City of Melbourne website: www.melbourne.vic.gov.au.

## References

ACE Architects' Council of Europe et al, 1999, ' A Green Vitruvius : principles and practice of sustainable architectural design', James and James (Science Publishers) Ltd, London .

Berge B, 2000, 'Ecology of BuildingMaterials', Architectural Press, Oxford .

Hes D, 2004, 'Council House 2 – Stories and lessons from the CH 2 project', Report for City of Melbourne .

Kibert C, 2005, 'Sustainable Construction – Green building design and delivery', John Wiley and Sons, Inc., New Jersey

Lawson, B, 1996, 'Building Materials, Energy and the Environment: towards ecologically sustainable development', Royal Australian Institute of Architects , Red Hill , A.C.T.

Ross J, 2003, 'Introduction to project alliancingon engineering and construction projects', publication of Project Control International Pty Ltd.

Thomas R, 1999, 'Environmental Design – An introduction for architects and engineers', E & FN Spon, New York

Wilson JL, Tagaza E, 2006, 'Green Buildings: Drivers and Barriers', Australian Journal of Structural Engineering, Vol 7 No 1, pp 57-64

Web References

Council House 2 (CH 2 ): www.melbour n e.vic.gov.au

Ecospecifier: www.ecospecifier.org

Green Building Council of Australia (GBCA): www.gbcaus.org

60L Building: www.60L.greenbuilding.com

## About the Authors

*Ms Clare Louise Newton*

Before commencing at The University of Melbourne, Clare Newton taught in both the Interior Design and Architecture courses at RMIT and was a Director of the architectural firm, Newton Hutson Pty Ltd. Her primary research and teaching interest is in the translation of architectural ideas into buildings. Currently, she is teaching Construction Technology and Architectural Design subjects in the undergraduate architecture course. In 1998, she received the Victorian NAWIC Award of Excellence for Innovation in Construction. Clare has been a Council Member of the Victorian Chapter of the RAIA (1998, 1999, 2000, 2001) and Chair of the RAIA Education Committee. She is an examiner for the Architects Registration Board of Victoria and a Tribunal member. She has been on RAIA award juries and was Chair of the Residential Category in 1998. Since 1997, she has been awarded approximately a quarter of a million dollars in seven multimedia and research grants and is currently working on multimedia projects exploring the evolution of design ideas into built form. Her research includes work into how the construction process is represented within architectural documents. This research has been shown locally and overseas at information visualisation conferences and history conferences. A new initiative by the co-authors has been to develop a Post-Graduate subject titled 'Sustainable Buildings' offered in the Masters Coursework Program at The University of Melbourne.

*John Wilson*

John Wilson is a Professor of Civil Engineering at Swinburne University of Technology in Melbourne. Prior to this appointment he was a senior academic at the University of Melbourne for some 14 years and a consulting engineer for over 10 years with the SECV and Arups in their London and Melbourne offices. He has a Bachelor of Engineering degree from Monash University, a Master of Science degree from University of California (Berkeley) and a PhD from University of Melbourne. He has a research interest and expertise in structural systems, earthquake engineering, structural dynamics and sustainable structures and has consulted widely in these fields. He was the Victorian Chairman of Engineers Australia in 2002, representing the professional interests of some 14,000 engineers and was a member of the steering committee for the 2005 Victorian Infrastructure Report Card.