Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Structural Engineering

Produced by

The University of Adelaide and Queensland University of Technology (The Natural Edge Project)

The EEERE Project:

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Consortium Partners:

Queensland University of Technology

The University of Adelaide

Victoria University Melbourne Australia

RMIT University

University of Wollongong

La Trobe University Australia

Project Partners:

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Project Background

Energy efficiency is widely recognised as the simplest and most cost-effective way to manage rising energy costs and reduce Australia's greenhouse gas emissions. Promoting and implementing energy efficiency measures across multiple sectors requires significant development and advancement of the knowledge and skills base in Australia, and around the world. Engineering has been specifically identified as a profession with opportunities to make substantial contributions to a clean and energy-efficient future. To further enable skills development in this field, the Department of Industry commissioned a consortium of Australian universities to collaboratively develop four innovative and highly targeted resources on energy efficiency assessments, for use within engineering curricula. These include the following resources informed by national stakeholder engagement workshops coordinated by RMIT:

1. *Ten **'flat-pack'** supporting teaching and learning notes for each of the key disciplines of engineering (University of Adelaide and Queensland University of Technology);*
2. *Ten short **'multi-media bite'** videos to compliment the flat-packs (Queensland University of Technology and the University of Adelaide);*
3. *Two **'deep-dive case studies'** including worked calculations (University of Wollongong); and*
4. *A '**virtual reality experience'** in an energy efficiency assessment (Victoria and LaTrobe Universities).*

These resources have been developed with reference to a 2012 investigation into engineering education[1] funded by the Australian Government's former Department of Resources, Energy and Tourism (RET), and through further consultation workshops with project partners and industry stakeholders. At these workshops, participants confirmed the need for urgent capacity building in energy efficiency assessments, accompanied by clear guidance for any resources developed, to readily incorporate them into existing courses and programs. Industry also confirmed three key graduate attributes of priority focus for these education resources, comprising the ability to: think in systems; communicate between and beyond engineering disciplines; and develop and communication the business case for energy efficiency opportunities.

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1. ‘Allen Key’ Learning Points (Following the Multi-Media Bite)

Structural Engineers will be a key part of the World’s response to climate change, from the design of civil infrastructure that is constructed with low embodied energy materials such as geo-polymer cements and recycled materials to buildings that use less artificial lighting and air-conditioning and even generate their own energy. Structural Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Structural Engineering video – our ‘Allen keys’ to building the flat-pack content!

Watch the ‘***Structural Engineering***’ MMB

1. There is growing pressure on Structural Engineers to assist in improving the energy efficiency of buildings, including: emerging ‘Green Building’ ratings schemes, changes in building regulations, and the expanding availability of innovative low carbon materials available to them. This means that in the coming decade Structural Engineers will be faced with the challenge of quickly embedding new practices into designs to respond to the need to reduce energy consumption.
2. An example of a green building is the Science and Engineering Centre at the Queensland University of Technology. One of the factors that lead to the University’s decision to build a high performance 5 star building was the opportunity to demonstrate best practice to students and the community, which also enhanced the profile of the university.
3. In a typical Brisbane CBD office building about 50% of electricity consumption is from air-conditioning, as opposed to just 30% in QUT’s green building. One of the improvements that lead to the improved performance was carefully designing and choosing materials for the façade. High performance glass was chosen to reduce the heat load on the building.
4. An interdisciplinary team of Structural, Environmental and Mechanical Engineers carefully examined every aspect of the façade to reduce the heat load. Energy and daylight modelling allowed engineers to maximise daylight while still keeping the amount of floor space required, and thereby reducing the amount of lighting required. As a result of compound savings, the team was ultimately able to reduce the size of the plant required for heating and cooling the building.
5. Energy Efficiency is going to continue to be very important topic for Structural Engineers. Some of the future challenges are going to include building infrastructure to withstand additional loads from storms and changes in weather variability, and challenges of materials availability due to the unsustainable use of resources.
6. If we are going to have a sustainable lifestyle then we are going to need Structural Engineers that understand the efficiency of structural engineering design, and how that impacts on the built environment and the world that we live in.

2. Energy Efficiency and Structural Engineering

2.1. Why is Energy Efficiency important for Engineers?

In the 21st Century much of the world will experience untold wealth and prosperity that could not even be conceived only a century ago.[2] However as with most, if not all, of the human civilisations, increases in prosperity and population have accumulated significant environmental impacts that threaten to result in what Lester Brown refers to as '*environmentally-induced economic decline*'.[3] There have been a number of significant advances in technology over the last 300 years that have delivered a step changes in the way industry and society has operated, as shown in Figure 1. Given the now advanced level of technological development we are in a very strong position to harness this technology to create a '6th Wave' that can deliver significant reductions in a range of environmental pressures, such as air pollution, solid waste, water extraction, biodiversity loss and greenhouse gas emissions.[4]

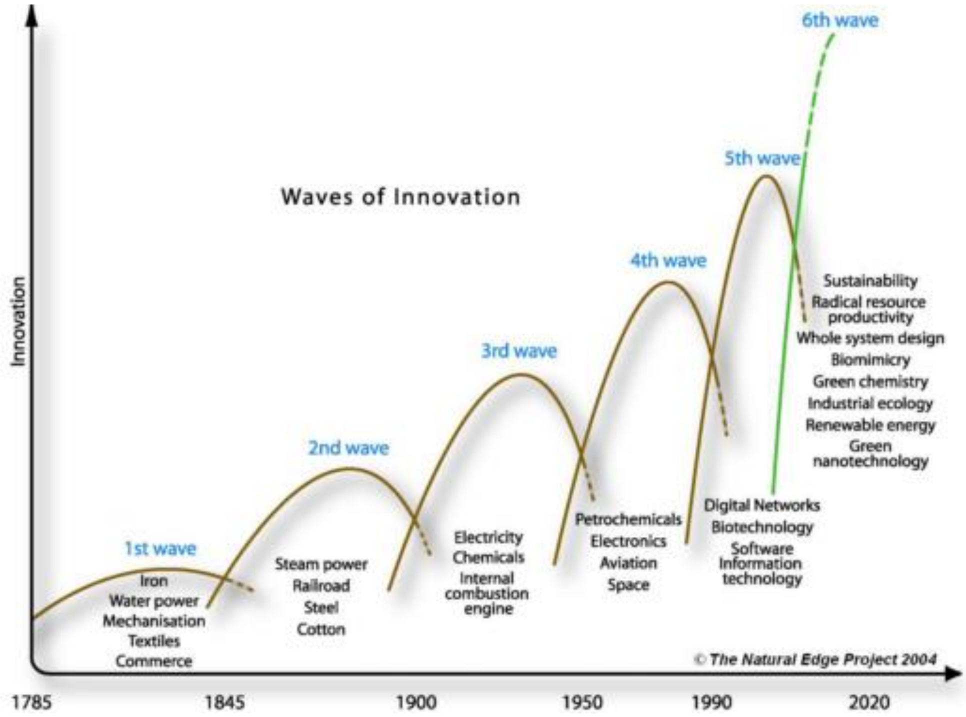

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

What this means is that over the coming decades the impact we are having on the environment will have a direct negative effect on our economies and societies, this will, and is, lead to louder and lauder calls to reduce negative impacts on the environment which will need innovation and creativity. Engineers will play a key role in assisting societies around the world, not only to reduce impacts on the environment, but to deliver positive environmental enhancement. In particular there is a fundamental need to shift from fossil fuel based energy to low/no carbon energy sources, preferably renewable options, in order to significantly reduce greenhouse gas emissions. Building on the technologies and processes from the previous waves of innovation Engineers are now in a strong position to deliver such a shift and create a range of innovative and creative solutions to the meet the needs of society, with a key part of this achieving greater efficiency of the use of resources and energy.

According to the World Business Council for Sustainable Development (WBCSD) in their 1992 publication 'Changing Course', the term 'efficiency' was used to seek to encapsulate the idea of using fewer resources and creating less waste and pollution while providing the same or better services, and entailed the following elements:

- A reduction in the material intensity of goods or services,
- A reduction in the energy intensity of goods or services,
- Reduced dispersion of toxic materials,
- Improved recyclability,
- Maximum use of renewable resources,
- Increased durability of products, and
- Greater service intensity of goods and services.

Each of these approaches provides valuable tools to reduce a range of environmental pressures, especially greenhouse gas emissions.

Identify a structural engineering example of the application of each element.

For each element identify the potential for collaboration with other engineers.

Since the late 1990's Engineers Australia has advocated for Engineers to play a key role in supporting the achievement of such ambitious targets, and cautions that, '*The need to make changes in the way energy is used and supplied throughout the world represents the greatest challenge to Engineers in moving toward sustainability.*'[6] By the end of 2014 this shift had built significant momentum with the European Union committing to reduce emissions by at least 40 per cent by 2030 (compared to 1990 levels), China setting the goal of 40 to 45 per cent by 2020 (compared to 2005 levels), India setting the goal of 20-25 per cent by 2020 (compared to 2005 levels), and the United States of America setting the goal of 26-28 per cent by 2025 (compared to 2005 levels). Further the Intergovernmental Panel on Climate Change (IPCC) reports that all nations will need to achieve significant reductions in greenhouse gas emissions in the order of 60-80 per cent by 2050.[7]

> ***These ambitious targets will create significant pressure to reduce emissions in the coming decades, in particular between 2015 and 2030; and all industries grapple with the challenge of reducing greenhouse gas emissions in a manner that delivers ongoing prosperity, jobs, and profits.***

A key part of this energy transition is to swiftly reduce the growing demand for energy across society as this will generate numerous cost savings that can be invested in the shift to low/no carbon energy, along with reducing demand levels that need to be met by the new energy solutions. Reducing the energy demand say of a building or a processing plant delivers the following benefits:

- *Generates cost savings* by reducing the energy charges, extending the life of equipment by reducing the loading, reducing operating times and levels of equipment and even allowing decommissioning of some equipment, and often reduces heat generated from equipment or lighting that adds load to the HVAC system.
- *Creates capital for investment* in the transition to the use of low/no carbon energy, often by investing in onsite renewable energy generation options that can harness waste heat from the existing system while providing security of supply for the operation of the building or plant.

- *Creates demand for new products and services* that will be needed around the world to assist industries and economies to reduce energy demand. This will translate into significant opportunities for Australian engineering firms that can innovate low/no carbon solutions ahead of international competition.[8]

Energy efficiency as a concept has gained significant attention over the last few decades, as governments and industries around the world have grappled with issues such as rapidly expanding needs for energy, the cost of supplying infrastructure to meet peak demand, the finite nature of fossil based energy reserves, and transition timeframes for expanding renewable energy supplies. Coupled with a growing number of cases of companies achieving significant fossil fuel consumption reductions in a timely and cost effective manner, energy efficiency is quickly becoming a core part of the practice of engineers, as shown in Table 1.

Where can Structural Engineers reduce greenhouse gas emissions?

How could energy efficiency provide benefits to a Structural Engineering firm?

Table 1: *Example opportunities to significantly reduce greenhouse gas emissions*

Sector	Best Practice Case Studies
Steel Industry[9]	Leading US steel company, Nucor Steel, is around 70% more energy efficient than many steel companies around the world,[10] using state-of-the-art electric arc furnace systems, adopting leading practices such as net shape casting, and by implementing options such as energy monitoring, systems for energy recovery and distribution between processes.[11]
Cement Industry[12]	Ordinary Portland cement manufacture is responsible for between 6-8% of global greenhouse emissions and this is rising with demand. The good news is that an Australian company Zeobond Pty Ltd, based in Melbourne, is now making geo-polymer cement which reduces energy usage and greenhouse gas emissions by over 80%.[13] Geo-polymers can be used for most major purposes for which Portland cement is currently used.[14]
Paper and Pulp Industry[15]	Catalyst Paper International improved their energy efficiency by 20% across all operations since 1990, saving the company close to US$26 million between 1994 and 2004. At the same time, they've reduced their greenhouse gas emissions by 69% through greater use of biomass and sourcing electricity from hydro power.[16] The pulp and paper sector has the potential in both existing and new mills to become renewable electricity power generators through the use of Black Liquor Gasification-Combined Cycle technologies.[17]
Transport Vehicle Efficiency[18]	Integrating technical advances in light-weighting, hybrid electric engines, batteries, regenerative breaking and aerodynamics is enabling numerous automotive and transport vehicle companies to redesign cars, motorbikes, trucks, trains, ships and aeroplanes to be significantly (50-80%) more fuel efficient than standard internal combustion vehicles. Plug-in vehicle technologies are opening up the potential for all transportation vehicles to be run on batteries charged by renewable energy.[19]
Transport Efficiency from Modal shifts. (Passenger)[20]	Shifting transport modes can also lead to significant energy efficiency gains. One bus with 25 passengers reduces energy and greenhouse gas emissions per capita by approximately 86% per kilometre compared to 25 single occupant vehicles (SOV).[21] Trains are even more efficient. Typically, rail systems in European cities are 7 times more energy-efficient than car travel in US cities.[22]
Transport Efficiency from Modal Shifts (Freight)[23]	Shifting freight transport from trucks to rail can also lead to large efficiency gains of between 75 and 85%.[24] Several countries are moving to improve the efficiency of their transport sectors by making large investments in rail freight infrastructure, including improving the modal interfaces. For instance, China has invested US$292 billion to improve and extend its rail network from 78,000 km in 2007, to over 120,000km by 2020, much of which will be dedicated to freight.

Source: Based on von Weizsäcker, Hargroves, K. *et al* (2009)[25] as presented in Hargroves, K., and Desha, C. (2014)[26]

Considering Buildings, efficiency expert Joseph Romm explains that key to delivering improved energy efficiency of buildings is the understanding that the design phase is critical, pointing out that, '*Although up-front building and design costs may represent only a fraction of the building's life-cycle costs, when just 1 per cent of a project's up-front costs are spent, up to 70 per cent of its life-cycle costs may already be committed*'.[27] As pointed out in the book '*Whole System Design: An Integrated Approach to Sustainable Engineering*',[28] the cost of design changes increases significantly through the design and construction process, and as such it is important that early in the concept design phase opportunities for energy efficiency are identified and incorporated into the design rather than retrofitted at a later date, especially as buildings and civil infrastructure are designed with an operational life of some 50-100 years.[29]

A key part of the design is to consider the potential for compounding energy efficiency savings. Energy efficiency expert Alan Pears uses the example of an electric motor driving a pump that circulates a liquid around an industrial site.[30] If each element in the chain is improved in efficiency by 10 percent, the overall efficiency is not improved by 10 per cent but rather 47 per cent as the overall efficiency is the product of the component efficiencies: 0.9 x 0.9 x 0.9 x 0.9 x 0.9 x 0.9 = 0.53. Applying this systems approach can deliver significant energy demand savings, such as:[31]

– By focusing first on reducing both the mass of a passenger vehicle and the aerodynamic drag by 50% this can reduce rolling resistance by 65%; making a fuel cell propulsion system viable and cost effective, and delivering significantly better fuel consumption per kilometre.

– By using the right-sized energy efficient components to reduce generated heat, a computer server can be designed to have 60% less mass and use 84% less power than the equivalent server, which would reduce cooling load in a data centre by 63%.

A key outcome of a focus on energy efficiency is that it often also delivers multiple benefits across the system can be often overlooked. For example energy efficient cleaning systems may use less water and detergents, light-weighting vehicles to improve fuel efficiency may reduce material consumption, reducing cooling loads in a building through external shading may extend the operating life of air-conditioning equipment, reducing pumping loads in a system may lead to decommissioning of unneeded pumps, reducing residential energy demand during peak times can significantly reduce overall capacity requirements and defer infrastructure upgrades.

2.2. Why is Energy Efficiency important for Engineering Students?

In 2006 the Australian Government created the Energy Efficiency Opportunities (EEO) Act with the objective to '*improve the identification, evaluation, and public reporting of energy efficiency opportunities by large energy-using businesses, to increase the uptake of cost effective energy efficiency opportunities*'.

Watch an Introduction to the EEO Program

The EEO Act was applicable to corporations that used over 0.5 petajoules of energy per year; this represented some 300 companies and just over half of Australia's total energy use. Participating companies were required to undertake an energy efficiency assessment and report to the government on the findings.

Between 2006 and June 2011 participants in the program identified the potential for annual energy savings of 164.2 PJ through a focus on energy efficiency across each major sector, as shown in Figure 2. As part of the program 89 PJ of energy was saved, the equivalent of 24 billion kWh's per year.

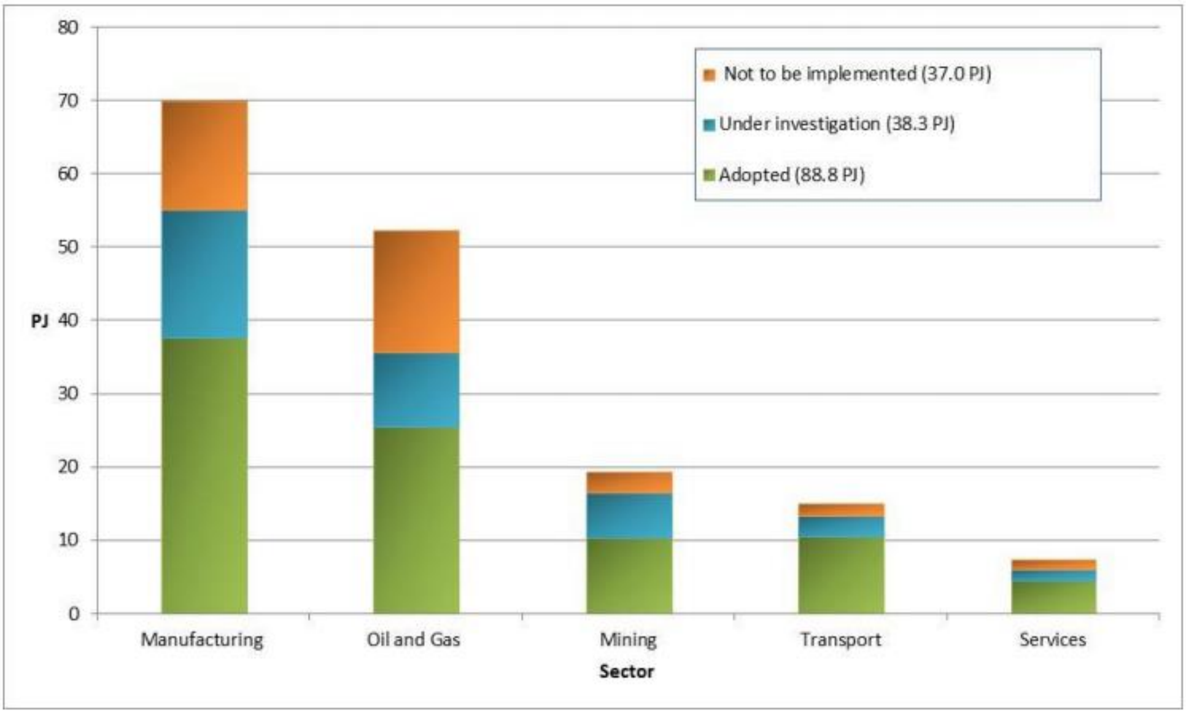

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

This energy saving is estimated to have resulted in an annual economic benefit of just over $800 million, with the majority of investments to achieve the energy savings having either a 1 year or 2 year return on investment.[33] The significance of this program for engineering students is that the largest energy using companies in the country have developed processes to undertaken energy efficiency assessments and the ability to contribute to such assessments is likely to become a part of graduate recruitment preferences given the strong economic results from the EEO program.

> ***In 2011 an investigation found that 6 out of the 10 largest engineering companies operating in Australia provided in-house training on energy efficiency to supplement graduates formal training, and 4 out of the 10 had included energy efficiency requirements in graduate recruitment criteria.[34]***

Of further interest to engineering students is that the participants in the program listed an aggregate of 38.3 PJ of energy saving opportunities (or some 10 billion KWh per year) as being 'under investigation', meaning that graduates can differentiate themselves by ensuring they are well versed in energy efficiency.

List a specific opportunity for Structural Engineers to achieve energy efficiency improvements in each of the sectors involved in the EEO Program (Figure 1).

3. Key Knowledge and Skills for Structural Engineers

According to the Institution of Civil Engineers the profession, '*plays a crucial role in creating the infrastructure needed for modern life around the world. Practitioners in the civil engineering sector apply knowledge and experience to create projects that meet human needs and clean up environmental problems*.'[35] Structural Engineering can offer a great deal to society to increase the energy efficiency of infrastructure, and reduce the associated greenhouse gas emissions, for instance by designing:

- Buildings with low embodied energy materials and optimal use of materials,
- Buildings with optimised energy demands, contributed to by onsite generation,
- Buildings that can be repurposed for multiple uses during or at the end of each use,
- Structures that can be easily disassembled to allow greater recycling rates,
- The use of natural features as design elements, such as green walls and roofs, and
- Emerging energy generation structures such as onshore and offshore wind turbines and large scale solar photovoltaic and solar thermal plants

In Structural Engineering, energy efficiency considerations could include:

- Design to minimise material use and incorporate low embodied energy materials into building structures (such as recycled aggregates, geo-polymer cements, and alternate structural materials),
- Ensuring quality and durability of materials used in built environment (reduces frequency of need to replace them), and
- Consideration of energy flows through materials, such as thermal bridging effects and use of insulating materials.

Engineering will play a key role in assisting society to respond to climate change, and in particular Structural Engineers have the opportunity to significantly reduce the energy demand of commercial buildings. As far back as 2001 The Institution of Engineers Australia's 'Sustainable Energy Building and Construction Taskforce' found that *'… energy neutral commercial building stock should be the goal to which industry and government should be now moving.'*[36] The energy demand of commercial buildings can be reduced in two key ways:[37]

1. The energy required to create the building, to adapt it to changing purposes, and to then decommission and recover the materials at the end of its life, and
2. The energy required for the building to operate over its lifetime (some 90% of energy demand[38]).

The first area related to building design is a significant opportunity for Structural Engineers to deliver improved energy efficiency and compliment efforts by Mechanical, Electrical, ITE Engineers to reduce energy use over the lifetime of the building. Preliminary research has also identified discipline-specific considerations that might be evident. In Structural Engineering this could include considerations for the use of natural lighting and clerestory windows; natural ventilation, shading and vegetated roofs; thermal regulation of buildings through the use of thermal mass and exposed concrete or masonry; design of roofs to receive the maximum benefit from installation of solar panels and the implications of all of the above for load bearing and load paths.

The following example energy efficiency elements/ indicators could be used:

– Knowledge of available technologies for ‘green’ buildings, and an understanding of how these elements influence structural design,

– Proficiency in calculating energy consumption in building materials processing, including production, use, and disposal phases, and

– Ability to identify energy efficiency opportunities in the design of buildings and selection of appropriate materials.

4. Energy Efficiency Examples in Structural Engineering

Here we provide a summary of key materials outlining energy efficiency opportunities related to Structural Engineering. This section informs ***'Tutorial Exercise 6: Identify examples of energy efficiency opportunities in particular engineering disciplines'*** *from the Introductory Flat-Pack.*

4.1. Low Carbon Cements: Geo-Polymers[i]

Geopolymer concrete is an alternative technology that can demonstrate significant reductions in carbon emissions compared to Portland cement, in the order of 45-80 per cent.[39] The US Federal Highway Administration have recently reported that '*the production of versatile, cost effective geopolymer cements that can be mixed and hardened essentially like Portland cement would represent a game changing advancement*'.[40] Geo-polymers utilise waste materials (including: fly ash and bottom ash from power stations; blast-furnace slag from iron-making plants; and concrete waste), to create alkali-activated cements. It demonstrates strong engineering performance, comparable to that of Portland cement concrete in structural applications. Geological resources for the feedstock are available on all continents, and recent studies of its use in the 1960s and 1970s in Ukraine and Russian buildings reveal it has better durability than Portland cement.[41] The manufacture of alkali activated binders omits the need for the bulk of the material to be processed in a kiln, thus greatly reducing greenhouse gas emissions. Only the silicate activator component (typically less than ten per cent of the binder mix) is super-heated in kilns, and a high proportion of industrial by-products, including fly ash and metallurgical slags, are added to complete the binder mix. In 2011 the Concrete Institute of Australia released a report that recommended the use of geo-polymer concrete by the construction industry.[42]

Australia is now among the world leaders in research and commercialisation of geo-polymer cement. After two decades developing the technology, University of Melbourne researchers formed Zeobond Pty Ltd in 2006 to commercialise it. They have created a new product called E-Crete that forms at room temperature, requires no kiln and uses industrial by-products as the main feedstock. The product looks similar to and performs in the same ways as Portland cement concrete. According to Zeobond Business Manager, Peter Duxson, '*As the scale of commercialisation is increased and more is invested in the supply chains, we expect the costs of making geo-polymer cements to come down significantly*'. [43] In February 2011, Queensland based Wagners introduced an innovative premixed concrete product that utilises geo-polymer binder technology. Winner of the 2011 Queensland Premiers ClimateSmart Sustainability Award the 'Earth Friendly Concrete' or EFC is reported to reduce the greenhouse gas emissions of a standard house slab and footings by just over 9 tonnes. Considering the number of slabs poured per year in Queensland this would represent nearly 275,000 tonnes a year of reduced greenhouse gas emissions compared to the use of Portland cement. [44]

This process, in which fly ash from coal power generation and blast furnace slag from iron production are converted into binders in place of the traditional Portland cement, not only utilises two materials that would otherwise have to be disposed of as industrial waste, it also reduces the carbon emissions of the concrete by 60-70 per cent compared to conventional concrete, and significantly lowers the embodied energy of the final product. The resultant emissions from the

[i] Based on research findings from the 'SBEnrc (2012) *Reducing the environmental impact of road construction*, Sustainable Built Environment National Research Centre, Curtin University Sustainability Policy Institute and Queensland University of Technology'.

production site are reduced by up to 90 per cent, and annual energy cost savings of around $2.7 million result from the process change, which no longer requires the process used for Portland cement – where limestone is heated to 1450°C in a kiln and is then finely ground – a process which produces equal weight of CO_2 and Portland cement.[45]

Why does Geo-Polymer cement create less greenhouse gas emissions than Portland cement? (Note that there are two main reasons)

4.2. Structural Design and Load Management

The heating load placed on HVAC system of a building can be reduced the Structural Engineering team, as pointed out in the book '*Factor 5: Transforming the Global Economy through 80% Improvements in Resource Productivity*':[46]

- *Building orientation and external shading:* The energy from the sun entering a building can be reduced through a focus on building orientation and shading. If appropriate the orientation of the building envelope should be set based on the solar gain of the site to balance heat entering the building during summer and winter. In the case where the building orientation is fixed due to site conditions the use of shading can reduce solar gain during summer and allow heat to enter the building during winter (using adjustable vertical shading for east and west façades).[47]
- *Windows:* Single glazed windows can transfer infrared (heat-containing) light wavelengths that heat building spaces unnecessarily. The specification of double glazed windows with gas filled spaces (usually air, argon, or krypton) significantly reduces heat transfer. Spectrally selective windows and films can also be used and can reject up to 98 per cent of infrared wavelengths and 99 per cent of ultraviolet wavelengths, while transmitting up to 70 per cent of visible wavelengths.[48] There are also several high performance glass types that can assist to further minimise energy consumption, including photochromic glass, thermochromic glass, electrochromic glass.[49] In addition, heat transfer across the window and building framing can be reduced by minimising thermal bridges, such as metal beams and studs, which are good thermal conductors.
- *Roofs:* In hot climates, heat transfer through the roof can be minimised by painting the roof a light colour, preferably white which has a solar reflectance of 80 per cent, or reflective white that has a solar reflectance of 95 per cent. The temperature on the surface of the roof can range from ambient temperature for a white surface to as much as 45°C for dark coloured roofs.[50] Unpainted galvanised roofs, while good reflectors of visible light wavelengths, are also good absorbers of the infrared (heat-containing) wavelengths and are thus not a good option for large roofs. In addition to reducing the cooling load, light coloured roofs and exterior walls also reduce the temperature of the surroundings, which is more pleasant for pedestrians and local wildlife.

Find three examples of Australian buildings that have used one or more of the design elements above to achieve energy demand reductions.

4.3. Incorporating Renewable Energy into Building Structures

In 2014 the Chinese government set the goal of reducing the nation's carbon emissions by 40-45 per cent by 2030, compared to 2005 levels. A sign of the innovation that this commitment will inspire comes from the Pearl River Tower in Guangzhou, China, that demonstrates how Structural Engineering can deliver innovative solutions to reducing greenhouse gas emissions. Along with reducing the anticipated energy demand by over 40 per cent the building incorporates wind turbines into the actual structure of the building (as shown in Figure 3), going a step further than simply incorporating solar panels into the façade, which it also does.[51] Not only do the wind turbines generate electricity the system also reduces the wind loading on the building affecting the overall structural design of the building, and as it is was the 59th tallest building in the world when it was built this is a key factor.

The building uses a number of structural design elements that reduces its energy consumption, and according to the designers '*Integrated design and engineering elements include solar panels, a double-skin curtain wall, a chilled ceiling system, underfloor air ventilation, and daylight harvesting. Collectively, these attributes will achieve significant energy savings and will reduce the tower's dependency on the city's infrastructure*'.[52]

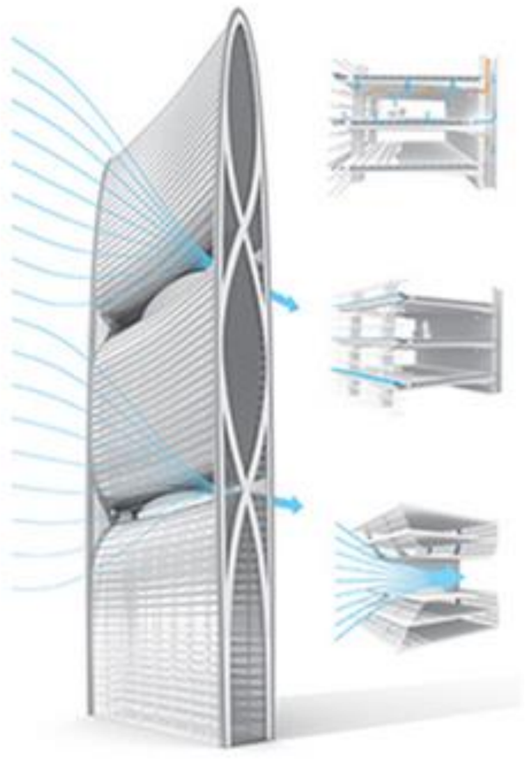

Figure 3: Pearl River Tower Airflow Schematic (*Source:* GreenBIM Engineering[53])

List 3 ways that renewable energy can be generated as part of the structure of commercial buildings and find a case study demonstrating each.

5. Case Studies of Structural Engineering and Energy Efficiency

Building on the multi-media bite on structural engineering and energy efficiency the following examples provide further details on the energy efficiency improvements related to Structural Engineering. This section is also designed to inform ***'Tutorial Exercise 7: Review industry case studies for areas of energy efficiency opportunities'*** *from the Introductory Flat-Pack.*

5.1. Retrofitting Existing Buildings

The University of Queensland's St Lucia Campus

Identification of the sources of inefficiency in a system is a great starting point for optimisation, but determining the level of energy usage associated with that source of inefficiency allows the overall impact to be assessed, and can help in prioritising the best starting points when improving efficiency. The University of Queensland's St Lucia campus provides an example of the gains that can be made through monitoring and assessment of existing systems. Through an energy audit, it was found that the air conditioning system on campus consumed approximately 45 per cent of all energy used on-site, and was seen as a good candidate for optimisation. The air chillers in the system were assessed by UQ's Energy Management Office, and it was found that the chillers were operating at acceptable efficiency only 20 per cent of the time.

The options available to improve efficiency were to replace the existing chillers with more efficient units, or optimise the control systems which operated the chillers. Due to cost and technical constraints, replacement was deemed too challenging, but through control optimisation, energy consumption by the air conditioning systems was reduced by 20 per cent, saving more than $100,00 per annum, and the optimisation is expected to pay for itself in less than 2 years. The advantages of undertaking such an energy audit are not solely related to energy savings, either – when the detailed assessment of energy usage was undertaken, it identified errors in billing related to tariffs and double-billing for some sites, and resulted in $1.45 million in refunds in 2012 alone.[54]

5.2. Design of New Buildings

Council House II - Australia[ii]

Council House II (CH2) is one the world's leading green buildings, and is one of the earliest 'Six Star' buildings under the Green Building Council of Australia's rating system (similar to a LEED Platinum rating).[55] According to the City of Melbourne, the building cost AUD$51 million (approximately US$39 million), including AUD$11.3 million (22 per cent), for sustainability features. Considering the AUD$1.45 million annual savings from such features, Council is expecting a pay-back period on the sustainability features of less than 10 years, and then ongoing savings.[56] The business case included an estimation of productivity benefits with regard to moving staff into the building, including the green retrofit measures. This was conservatively estimated to be 4.8 per cent per year over 20 years for the financing calculations, which when capitalised into the building costs allowed the project to spend an extra AUD$25 million on innovations. An independent productivity survey undertaken in 2008 found the financial yield to be much higher for CH2 than the minimum required - coming in at 10.8 per cent (AUD$2.4 million per year, or $270 per m^2 for the 9,000m^2 of floor space, which is almost as much as the rent that they pay).[57] Thus, the report confirms that the productivity of office

[ii] Extract adapted from von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) *Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity*, Earthscan, UK

building occupants can potentially be significantly enhanced, translating to financial benefit, through good building design, and provision of a high quality, healthy, comfortable and functional interior environment.[58]

(a) (b) (c)

Figure 4: (a) Operable external shading (b) Evaporative Cooling System –Shower Towers, and (c) Variant Façade and Window Dimensioning. (*Source:* Melbourne City Council)

The integrative design process for the CH2 building began in January 2002 when the design team converged in a two-week intensive charrette led by the lead Architect Mick Pearce to develop a workable schematic design.[59] The collaborative design process for CH2 enabled innovative decisions to be balanced by an acceptable level of certainty regarding constructability and cost. To achieve high levels of energy efficiency, the design team were charged with the task of ensuring that CH2 achieved at least a 5 star energy level.[60] The building consumes 82 per cent less energy than the first Council building, has reduced gas consumption by 87 per cent, produces only 13 per cent of the emissions, and reduces demand on the water mains supply by 72 per cent. Key structural engineering design features of Council House II include:[61]

a) *Operable External Shading*: The high thermal mass of the building, along with shading mechanisms on the sun-exposed sides of the building effectively prevent heat from penetrating the building during the day, reducing reliance on air-conditioning. The western façade has louvers made from recycled timber that move according to the position of the sun and are powered by photovoltaic roof panels. Windows on the northern and southern façades are automatically opened at night to purge the building with fresh, cool air. (See Figure 4(a))

b) *Evaporative Cooling System – Shower Towers*: The evaporative cooling system used in the building is incorporated into the structure of the building through the placement of five 'shower towers' that are 13 metres high and 1.4 metres in diameter. The air from the first 3 floors is drawn into the towers and cooled by a water shower and drops into lobby of the building.

c) *Variant Façade and Windows Dimensioning*: A key structural engineering design element of the building is the variant façade and window dimensioning. As can be seen from Figure 4(c) the size of the windows decreases from street level up to the top floor to reduce the incoming heat, while the size of the air ventilation ducts increases as it is progressively drawing from additional floors on the way up. These to geometric needs align well to provide structural function and a pleasing aesthetic.

Since the construction of the CH2 building in 2006 how much energy has it saved compared to a traditional design?

QUT Science and Engineering Centre

The Science and Engineering Centre at QUT achieved a 5-star Green Star rating upon completion in 2012. The $230 million project began in 2008 and features learning and research spaces, a two-storey interactive digital learning and display screens called 'The Cube', food and retail spaces, a 50-metre swimming pool and gym, a large public forecourt to Old Government House, and pedestrian link from Goodwill Bridge to the Brisbane Botanic Gardens. The QUT Science and Engineering Centre endeavours to teach students about sustainable building design by incorporating interactive display screens showing the building's real time energy usage, and display windows into areas usually hidden such as the engine room. The building features a number of structural elements that improve the overall energy efficiency and reduce greenhouse gas emissions, namely:

a) *Precast concrete panels*: The outside walls of the QUT Science and Engineering Centre use precast concrete panels. Unlike standard concrete walls which are poured on site, precast concrete panels are produces in factory controlled conditions off site and then transported to the site. This allows for enhanced quality control during the mixing and curing of the concrete. Precast panels also avoid a lot of form ply wastage as they are cast into reusable steel moulds. (Image Source: QUT[62])

b) *Façade Design*: The design of a building's facade greatly influences its demand for cooling and heating to keep the inside environment comfortable. Heating and air-conditioning are responsible for up to 50% of a building's energy usage. A facade which keeps heat out during the summer, and heat in during the winter, requires less artificial thermal control and has reduced electricity costs. The QUT Science and Engineering Centre is clad with 1200 insulated glazing units (IGU) or glass panels. Each IGU is about 33 mm thick and consists of two glass panes separated by a 12 mm argon gas filled space. The argon layer provides insulation.[63] The orientation of a building with regards to the sun can influence heat absorption and energy demand. The NW and SW facades of the building were found to have the highest energy demand in the SEC, and consequently require a higher performing facade.

c) *Glazing*: For a glass facade, glazing parameters are an important determinant of energy performance. Three parameters include U Value (representing the ability to conduct heat), Solar Heat Gain Coefficient or SHGC (representing the amount of solar radiation entering the building) and the Visible Light Transmittance or VLT (representing the amount of visible light entering the building). The optimum levels for each parameter are unique for every situation. For the QUT Science and Engineering Centre it was found that good thermal energy performance and thermal comfort could be achieved at U Value = 1.8 W/m2K, SHGC = 0.3, and VLT = 0.6.[64]

d) *Self-climbing jump system:* Many tall buildings are constructed using self-climbing jump systems. These provide both formwork and scaffolding. A self-climbing jump system was used for construction of the lift shafts in the QUT Science and Engineering Centre. This system allowed construction to proceed on the lift shaft without having to wait for support from other parts of the building. This increased the efficiency of the build and reduced labour and crane hire time requirements. The self-climbing jump system also promotes safety with its stable working platforms and high load-bearing capacity.

e) *Steel cross-bracing:* Levels 4-9 of 'Y Block' of the QUT Science and Engineering Centre employ cross-bracing of structural steel. Structural steel is used for its superior strength-to-weight ratio, meaning that savings can be made elsewhere, such as with the thickness of concrete columns.

Figure 6: Structural steel cross-bracing used in the QUT Science and Engineering Centre (*Source*: QUT)

University of Adelaide Ingkarni Wardli Building

Structural engineering, particularly on large projects, offers significant opportunities for improving efficiency, saving energy and money simultaneously. Examining a structure using a whole-system approach can lead to great opportunities for improving energy efficiency – the Ingkarni Wardli building on the North Terrace campus provides a great example of this. As the first Australian building project to achieve a 6-star rating from the Green Building Council for education buildings, the building features a number of efficiency-enhancing technologies. Structural features include:

1. Active slab hydronic cooling of the floor slabs and use of geothermal loops to remove heat from computer server rooms,
2. Integration of thermal chimneys which provide passive air handling through convection, and
3. A double-glazed curtain wall that insulates the building while allowing natural light entrance.

All of these minimise the energy requirements of the building, and increase its efficiency.

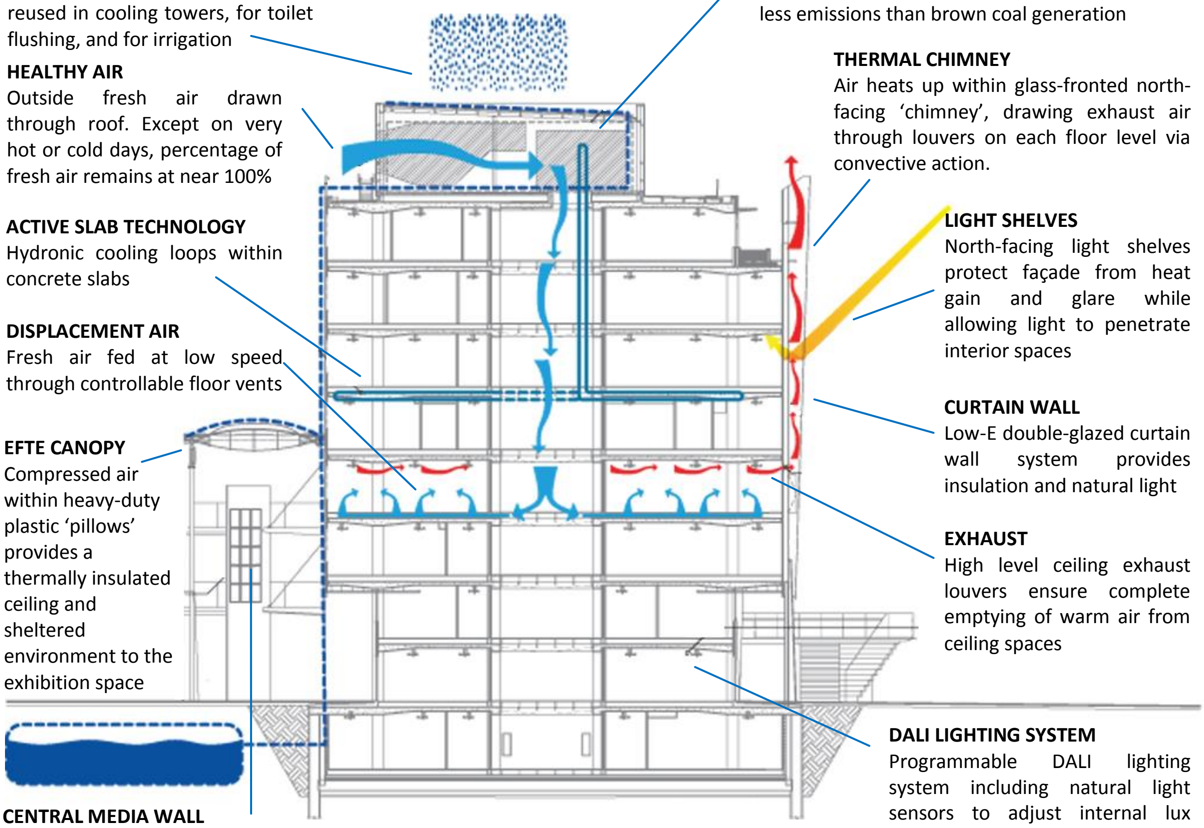

Figure 5: Innova21 / Ingkarni Wardli Design Features (*Source:* University of Adelaide[65])

The energy that is required by the building is further minimised through integration of programmable lighting systems which are designed to minimise energy waste through lights left on when rooms are unoccupied, while the building is powered by an on-site tri-generation plant on the roof, which produces electricity using a gas generator, and then uses the exhaust heat to provide both heating and cooling through the use of an absorption chiller, with emissions levels that are 17 per cent lower than coal-fired power. In such a design, each level of the system, from individual lights, through power production, through to the design of the building structure itself, are interlinked, and the whole design is more efficient as a result.[66] The advantages of using such materials are not solely environmental either – when compared to traditional concrete, EFC has significant performance advantages as a structural material, including improved durability, increased fire resistance and higher flexural tensile strength, in turn offering greater design freedom to the engineer.[67]

6. Key Supporting Resources

The following resources are recommended by the research team to assist lecturers to expand the content contained in this introductory level lecture. For guidance as to embedding such materials into existing course see the 2014 book 'Higher Education and Sustainable Development: A Model for Curriculum Renewal'.[68]

6.1. The Natural Edge Project

Opportunities for Energy Efficiency in Commercial Buildings: This lecture aims to review the energy efficiency opportunities in commercial buildings and covers key components of design, selection and operation of various resources and systems. This lecture focuses on energy efficiency opportunities in lighting and embodied energy.[69] (See Resource)

Commercial Building Energy Efficiency and Renewable Energy Opportunities: The aim of this lecture is to demonstrate the benefits of front-loaded design, and to demonstrate the opportunity for Australian built environment professionals to show leadership in sustainable designs.[70] (See Resource)

References

[1] Desha, C. and Hargroves, K. (2012) *Report on Engineering Education Consultation 2012*, a report and accompanying Briefing Note, Australian Government Department of Resources, Energy and Tourism, Canberra.

[2] Hargroves, K., and Desha, C. (2014) 'Energy Productivity and Decarbonization of the Global Economy: Factor Five Resource Productivity', *Energy and Environment*, WENE-217, Wiley Interdisciplinary Reviews.

[3] Brown, L.R. (2008) Plan B 3.0: Mobilizing to Save Civilization, W.W. Norton & Company, New York.

[4] Smith, M., Hargroves, K. and Desha, C. (2010) *Cents and Sustainability: Securing Our Common Future through Decoupling Economic Growth from Environmental Pressure*, Earthscan, London.

[5] Hargroves, K. and Smith, M. (authors and eds) (2005) *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, Earthscan/Routledge, The Natural Edge Project, London.

[6] Engineers Australia (1997) *Towards Sustainable Engineering Practice: Engineering Frameworks for Sustainability*, Engineers Australia, Canberra, Australia.

[7] IPCC (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the International Panel on Climate Change, Cambridge University Press, Cambridge.

[8] Desha, C., Hargroves, K., and Smith, M. (2009) '*Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development*', International Journal of Sustainability in Higher Education, vol 10, no 2, pp184-199.

[9] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 3.

[10] Boyd, B.K. and Gove, S. (2000) 'Nucor Corporation and the U.S. Steel Industry', in Hitt, M.A., Ireland, R.D. and Hoskisson, R.E. (eds) Strategic Management: Competitiveness and Globalization, 4 Edition, Southwestern Publishing.

[11] Worrell, E., Price, L. and Galitsky, C. (2004) Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California, USA.

[12] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 3.

[13] The Natural Edge Project (2009) 'Factor 5 in Eco-Cements', CSIRO ECOS Magazine, Issue 149.

[14] CSIRO (undated) 'Geopolymers: Building Blocks of the Future', www.csiro.au/science/ps19e.html, accessed 30 October 2014.

[15] See Smith, M., Hargroves, K., Desha, C. and Stasinopoulos, P. (2009) *Factor 5: The Pulp and Paper Online Sector Study*, The Natural Edge Project, Australia.

[16] von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany.

[17] Worrel, E., Price, L. and Galitsky, C. (2004) Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California, USA.

[18] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[19] Light Rail Now (2008) 'CTrain Light Rail growth continues with North East extension', News Release, January 2008, Light Rail Now, Texas, USA.

[20] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[21] Northern Territory Government (2007) 'NT Greenhouse Gas Emissions - Transport' http://www.nt.gov.au/nreta/environment/greenhouse/emissions/transport.html, accessed 4 April 2010.

[22] Newman, P. and Kenworthy, J. (2007) 'Transportation energy in global cities: sustainability comes in from the cold', Natural resources forum, vol 25, no 2, pp91-107.

[23] See von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK and Droemer, Germany, Chapter 5.

[24] Frey, C. and Kuo, P. (2007) 'Assessment of Potential Reduction in Greenhouse Gas (GHG) Emissions in Freight Transportation', Proceedings, International Emission Inventory Conference, US Environmental Protection Agency, Raleigh, NC, May 15-17, 2007.

[25] von Weizsacker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Improvements in Resource Productivity, Earthscan, London.

[26] Hargroves, K., and Desha, C. (2014) 'Energy Productivity and Decarbonization of the Global Economy: Factor Five Resource Productivity', Energy and Environment, WENE-217, Wiley Interdisciplinary Reviews.

[27] Romm, J. (1994) cited in Hawken, P., Lovins, A. and Lovins, H. (1999) *Natural Capitalism: Creating the Next Industrial Revolution*, Earthscan, London, Chapter 6:' Tunnelling Through the Cost Barrier'.

[28] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[29] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[30] Pears, A. (2004) *Energy Efficiency – Its potential: some perspectives and experiences*, Background paper for International Energy Agency Energy Efficiency Workshop, Paris, April 2004.

[31] Stasinopoulos, P., Smith, M., Hargroves, K. and Desha, C. (2008) Whole System Design: An Integrated Approach to Sustainable Engineering, The Natural Edge Project, Earthscan, London.

[32] Australian Government (2013) Energy Efficiency Opportunities Program, The First Five Years: 2006–2011, Overview., Commonwealth of Australia.

[33] Australian Government (2013) Energy Efficiency Opportunities Program, The First Five Years: 2006–2011, Overview., Commonwealth of Australia.

[34] Desha, C., Hargroves, K. and El Baghdadi, O. (2012) 'Review of Postgraduate Energy Efficiency Course Content and Recommendations for Use of Existing Course: Vocational Graduate Certificate in Building Energy Analysis (Non-Residential)', Report to the National Framework for Energy Efficiency, The Natural Edge Project (TNEP), Australia

[35] Insititution of Civil Engineers (2014), 'Environment and Sustainability Knowledge', http://www.ice.org.uk/topics/environment/Energy-reports, accessed 28 November 2014

[36] Engineers Australia (2001) *Sustainable Energy Innovation in the Commercial Building Sector: The Challenge of a New Culture*, Sustainable Energy Building and Construction Taskforce Report, Engineers Australia.

[37] von Weizsacker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Improvements in Resource Productivity, Earthscan, London.

[38] AGO (1999) *Australian Commercial Building Sector Greenhouse Gas Emissions 1990-2010,* Australian Greenhouse Office.

[39] McGuire, E., Provis, J., Duxson, P., & Crawford, R. (2011) 'Geopolymer Concrete: Is there an alternative and viable technology in the concrete sector which reduces carbon emissions?'

[40] Federal Highway Administration (2010) 'TechBrief - Geopolymer Concrete', www.fhwa.dot.gov/pavement/concrete/pubs/hif10014/hif10014.pdf, accessed 24 January 2012

[41] Xu, H., Provis, J.L., van Deventer, J., & Krivenko, P.V. (2008) 'Characterization of aged slag concretes', *ACI Materials Journal*, March–April 2008. As cited in Smith, M., Hargroves, K., Desha, C., & Stasinopoulos, P. (2009) 'Factor 5 in eco-cement: Zeobond Pty Ltd.', *ECOS Magazine*, www.ecosmagazine.com/?paper=EC149p21, accessed 24 January 2012

[42] Concrete Institute of Australia (2011) *CIA Z16-2011 Geopolymer Recommended Practice Handbook*, Concrete Institute of Australia, Australia

[43] Smith, M., Hargroves, K., Desha, C., & Stasinopoulos, P. (2009) 'Factor 5 in eco-cement: Zeobond Pty Ltd.', *ECOS Magazine*, www.ecosmagazine.com/?paper=EC149p21, accessed 24 January 2012

[44] Wagners (2012) Earth Friendly Concrete, Wagners Concrete PtyLtd.

[45] Wagners Concrete 2012, *Earth Friendly Concrete,* Wagners Concrete Pty Ltd, Toowoomba, Australia

[46] von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity, Earthscan, UK.

[47] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C. and Hargroves, S. (2007) *Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation*, The Natural Edge Project (TNEP), Australia, see Lecture 2.3.

[48] Abraham, L.E. (1996) 'Daylighting', in Public Technology Inc. and US Green Building Council (1996) *Sustainable Building Technical Manual*, Public Technology Inc., ppiv.7-iv.20, www.smartcommunities.ncat.org/pdf/sbt.pdf, accessed 29 August 2007.

[49] Abraham, L.E. (1996) 'Daylighting', in Public Technology Inc. and US Green Building Council (1996) *Sustainable Building Technical Manual*, Public Technology Inc., ppiv.7-iv.20, www.smartcommunities.ncat.org/pdf/sbt.pdf, accessed 29 August 2007.

[50] Merritt, F.S. and Ricketts, J.T. (2001) *Building Design and Construction Handbook*, 6th Edition, McGraw-Hill, pp13 and 38.

[51] Gonchar, J (2013) 'Towering Ambition: The architects and engineers behind an office building in rapidly expanding Guangzhou put super green before supertall', Architectural Record, April 2013.

[52] SOM (n.d) Pearl River tower – Sustainable Design, http://www.som.com/projects/pearl_river_tower__sustainable_design#sthash.IPFkmUkM.dpuf, accessed 07 December 2014.

[53] Architecture and Design (2012), 'Innova21, University of Adelaide', http://www.architectureanddesign.com.au/the-book/projects/sustainable/innova21-university-of-adelaide#, accessed 28 November 2014

[54] Department of Industry 2013, *Energy Efficiency at the University of Queensland Case Study*, Australian Government, Canberra

[55] Fortmeyer, R. (2008) 'The Council House 2 (CH2) 'Building', *Grandbuild.com (Technology),* August 14, 2008, http://grandbuild.ashui.com/2008/08/the-council-house-2-ch2-building, accessed 20 March 2009.

[56] City of Melbourne (2007) 'Eco-Building Cuts CO_2 87%, Electricity 82%, Gas 87% and Water 72%: Eco-Building - Council House 2 (CH2) New Municipal Office Building', Case Study presented at C40 Large Cities Climate Summit, New York City, 2007, www.c40cities.org/docs/casestudies/buildings/melbourne_eco.pdf, accessed 23 March 2009.

[57] Wall, C. (2008) 'Australia's Green Revolution', Presentation to the Think 08 Conference on Sustainability in the Built Environment, 7-8 May 2008, London. Address available on You Tube www.youtube.com/watch?v=ScQdgU_kfzw&feature=related, accessed 23 March 2009.

[58] Paevere, P. and Brown, S. (2008) *Indoor Environment Quality and Occupant Productivity in the CH2 Building: Post-Occupancy Summary,* Report no USP2007/23, CSIRO, Australia, p20.

[59] Malin, N. (2004) 'Integrated Design', *Environmental Building News*, vol 13, No. 11.

[60] Cheung, C.K. (2005) *CH2 Energy Harvesting Systems: Economic Use and Efficiency*, Built Environment Research Group, Deakin University, Australia, www.melbourne.vic.gov.au/rsrc/PDFs/CH2/Study6TechnicalPaper_updated.DOC, accessed 9 August 2008.

[61] Department of Environment and Water Resources (2007) *ESD Design Guide: Office and Public Buildings*, 3rd Edition, DEWR, Australia, www.c40cities.org/docs/casestudies/buildings/melbourne_eco.pdf, accessed 23 March 2009.

[62] Content sourced from QUT News Web Service, (2011), *Precast concrete walls* [ONLINE]. Available at:http://www2.qut.edu.au/sci-eng-centre/news/news-event.jsp?news-event-id=39283 [Accessed 11 April 14].

[63] QUT News Web Service. 2012. *Construction update: 27 April 2012*.

[64] Kovachevich, A K, (2009) *QUT Science and Technology Precinct and Community Hub: Assessment of ESD Opportunities*. Brisbane: EMF Griffith.

[65] Architecture and Design (2012), 'Innova21, University of Adelaide', http://www.architectureanddesign.com.au/the-book/projects/sustainable/innova21-university-of-adelaide#, accesed 28 November 2014

[66] Architecture and Design (2012), 'Innova21, University of Adelaide', http://www.architectureanddesign.com.au/the-book/projects/sustainable/innova21-university-of-adelaide#, accesed 28 November 2014 University of Adelaide (2014), 'Ingkarni Wardli Design Features', http://www.ecms.adelaide.edu.au/about/ingkarni-wardli/design-features/, accessed 28 November 2014

[67] Wagners Concrete 2012, *Earth Friendly Concrete,* Wagners Concrete Pty Ltd, Toowoomba, Australia

[68] Desha, C., and Hargroves, K (2014) *Higher Education and Sustainable Development: A Model for Curriculum Renewal*, Earthscan, Routledge.

[69] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007), *Lecture 2.2: Opportunities for Energy Efficiency in Commercial Buildings*, The Natural Edge Project, Australia

[70] Smith, M., Hargroves, K., Stasinopoulos, P., Stephens, R., Desha, C., and Hargroves, S. (2007), *Lecture 9.2: Commercial Building Energy Efficiency and Renewable Energy Opportunities*, The Natural Edge Project, Australia