# DEEP DIVE CASE STUDY:

## Building Energy Use Analysis and System Design for Energy Efficiency and Sustainability

## Supporting Material

Project EEERE:

**E**nergy **E**fficiency **E**ducation **R**esources for **E**ngineering

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Queensland University of Technology
The University of Adelaide
Victoria University Melbourne Australia
RMIT University
University of Wollongong
La Trobe University Australia

**Project Partners:**

Engineers Australia
aced
Australasian Association for Engineering Education
energy efficiency council
asbec Australian Sustainable Built Environment Council

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## Citation Details

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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. 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. This includes:

1. Ten short **'multi-media bite'** videos for each engineering college of Engineers Australia and an introduction (led by Queensland University of Technology with the University of Adelaide);
2. Ten **'flat-pack'** supporting teaching and learning notes (led by University of Adelaide with QUT);
3. Two **'deep-dive case studies'** including worked calculations (led by University of Wollongong); and
4. A '**virtual reality experience'** in an energy efficiency assessment (led by Victoria University).

Specifically, these resources address the graduate attributes of '**identifying**', '**evaluating**' and '**implementing**' energy efficiency opportunities in the workplace, incorporating a range of common and discipline specific, technical and enabling (non-technical) knowledge and skill areas. The four resources were developed with reference to the 2012 Industry Consultation Report and Briefing Note [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 a business case** for energy efficiency opportunities.

[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.

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# 1 Introduction

Australia generates about 1.5% of global greenhouse gas emissions. However, on a per capita basis, Australia is one of the world's largest polluters[2]. It is reported that 23% of Australia's total greenhouse gas emissions are a result of energy demand in buildings[3]. The rapid enhancement of energy efficiency in the building sector is essential for a timely reduction in global energy use and promotion of environmental sustainability. Appropriate building energy use analysis and system design are among the key steps towards building energy efficiency and sustainability.

This document outlines a *Deep Dive Case Study* analysing energy efficiency in commercial building services design. Based on provided or selected building parameters (location, geometry, etc.), the case study looks at building energy use, water pumping system design, and air duct system design and the subsequent impact on energy efficiency. While the latter of these technologies are specific within a building, the approach of the case study attempts to remain holistic to establish the impact of specific design decisions on the overall energy use, and subsequently, energy efficiency in the broader sense as an engineering challenge.

This deep dive case study will demonstrate how to analyse building energy use to identify possible technical options to reduce building energy consumption, and optimise the design of the air duct system and water pumping systems in heating, ventilation, and air-conditioning (HVAC) systems. It will illustrate how to determine the optimal pipe/duct size and select appropriate water pumps/ventilation fans under the given design conditions to achieve energy efficiency.

This document provides an overview and objectives for engineering faculties, addressing:

- Graduate attributes and learning outcomes (both technical and enabling) to be developed through using this resource.
- Potential learning pathways for developing the identified knowledge and skills.
- How the learning outcomes link to Engineers Australia accreditation requirements and Stage 1 competencies.
- How the learning outcomes link to other high order competencies, such as improvements in graduates' abilities to conceptualise energy efficiency issues, and to work in multi-disciplinary teams to assess and implement energy efficiency opportunities (e.g. with accountants etc.).
- How the resources and the learning outcomes will produce graduates that are more job-ready in relation to energy efficiency assessment, management, monitoring, project analysis and implementation.
- The engineering sub-disciplines for which the resources are relevant.

The document also provides information regarding guidance documents or advice for lecturers to:

- Provide practical guidance or advice to lecturers and faculties wishing to incorporate the resources, and
- Support lecturers' practical understanding of energy efficiency in an industrial context, and their capacity to teach it effectively.

[2] http://www.carbonneutral.com.au/climate-change/australian-emissions.html, accessed 10 Dec. 2013
[3] CIE, Capitalising on the building sector's potential to lessen the costs of a broad based GHG emissions cut, Centre for International Economics (CIE), Canberra & Sydney, Australia, September 2007

# 2 Statement of coverage

## 2.1 Resource focus

The case study was developed with three different levels of technical details, knowledge and skills, as illustrated in Figure 2.1. Level 1 focuses on building energy use analysis. Based on given building geometry and design conditions, the students can act as a building services system designer to estimate the energy use of different building components, such as lighting, air-conditioning, office equipment, etc. The students can also estimate building energy performance enhancement through changing lighting energy use intensity, window-to-wall ratio, the inclusion of additional insulation layers for building façade, etc.

Level 2 mainly focuses on the water pumping system design, including pressure drop calculation, pipe sizing and water pump selection. Level 3 focuses on the air duct system design, including calculation of pressure drop across each individual component in an air duct system and selection of appropriate ventilation fans for energy efficiency. Level 2 and Level 3 will use a problem-based learning approach to highlighting engineering considerations in the design of water pumping systems/air duct systems and selection of water pumps/ventilation fans.

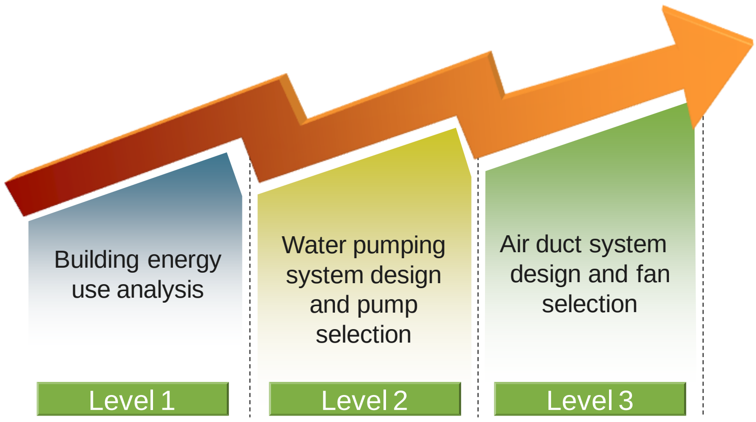


**Figure 2.1 - Illustration of the three-level deep dive case study**

The *Deep Dive Case Study* simulation and software platform utilises Microsoft Office Excel (2010 and above) and Visual Basic Application. The software platform is provided "unlocked" to ensure educators and students can investigate all aspects of calculation and simulation. This platform is utilised to enable the case study to be expanded through the creation of additional themes or entirely new case studies, e.g.:

- Integration of different control strategies for water pumps and ventilation fans;
- Tuning of the parameters of the PID controllers for variable speed fans and water pumps; and
- Integration of the central plant such as chillers, heat pumps, etc.

Level 1 of the *Deep Dive Case Study* software is a single level worksheet and provides a general understanding of the impacts on building energy usage from different aspects including building constructions, internal gains and operation schedules. The software is able to run simulation according to user defined inputs and demonstrate current and last run results graphically in terms of total annual energy consumption and energy breakdown. This part of the software is also designed to calculate design cooling load based on the design conditions which will be used in the air duct and water pumping system design and optimisation.

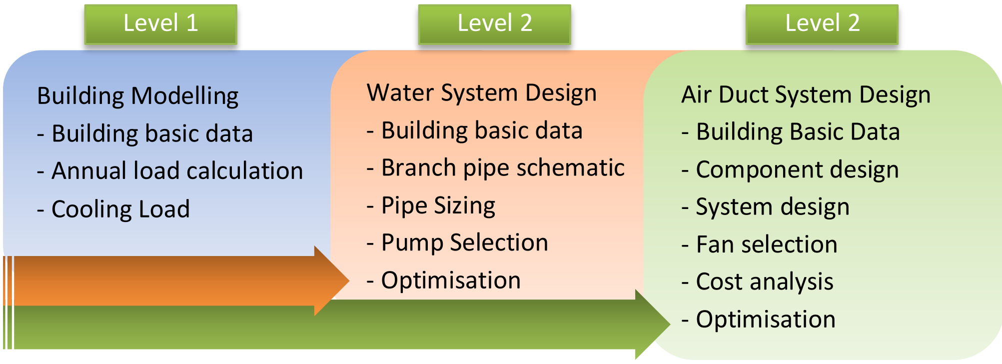


**Figure 2.2 - Illustration of the three-level deep dive case study**

Level 2 of the software enables the design and optimisation of the water pumping system in an air-conditioning system of the *Deep Dive Case Study*. Chilled water pumping system design and optimisation mainly include the water pipe sizing and pump selection based on the given design load. There are two parts in the water pumping system design, i.e. inputs and outputs. With the correct inputs, the index circuit, initial and operating costs will be determined.

Level 3 of the software summarises the design and optimisation of the air duct system in an air-conditioning system. The air system design is achieved as a multi-level process, by navigating through three separate spreadsheets, i.e. 'System Design', 'Fan Selection' and 'Cost Analysis'. Users can select different duct sizes, duct materials and fittings in the system design to determine the best design option based on life-cycle cost analysis. Determining a suitable design or optimising for energy efficiency (or other targets) enables the task to be either simple or a higher level of complexity.

Level 1 and Level 3 worksheets utilise data from Level 1 to ensure continuity of the *Deep Dive Case Study*. Further details of the operation and background theory for the *Deep Dive Case Study* simulation software are provided in the *Companion Document*.

## 2.2 Relevant industry sectors

The industry sectors included within this *Deep Dive Case Study* are the following:

- Commercial building design
- Building services
- HVAC systems
- Mechanical design

## 2.3 Relevant technologies

The key technologies to be covered in the *Deep Dive Case Study* include ventilation systems, lighting systems, fans, water pumps and HVAC systems. A range of scenarios below can be covered and tested in this case study:

- Estimate the energy use of different building components based on given design conditions and current building design standards;
- Analyse building energy performance enhancement through using different energy efficiency lighting products and the inclusion of additional insulation layers for building facades;
- Calculate the pressure drop across each individual component of an chilled/hot water system under different pipe sizes;

- Determine the optimal pipe size and select the best water pump by using life-cycle cost analysis; and
- Determine the pressure drop across each individual component of an air duct and distribution system.

Visual display of component and system design is included in the *Deep Dive Case Study* simulation and software platform to ensure the students have obtain some authenticity to the design decisions they are making. Refer to example below.

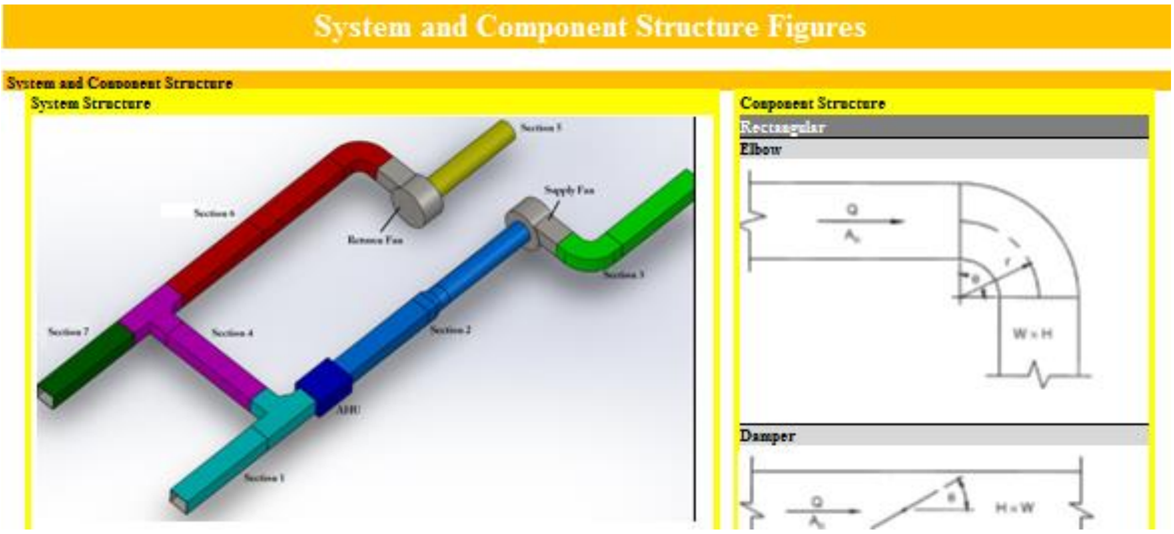


Figure 2.3 - Some information in the “Help” sheet.

## 2.4 Graduate outcomes

The learning outcomes achieved from students will be dependent on how educators choose to utilise the *Deep Dive Case Study* simulation and software platform. Generally, students completing tasks utilising the *Deep Dive Case Study* will gain an understanding of the impact of various design decisions on commercial building services energy use and gained knowledge of building design principles in general.

In the area of building energy use the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. insulation, windows-to- wall ratio, operation schedule, etc.) on building energy use;
- Understand how to optimise the building design to reduce energy consumption; and
- Understand how to determine the design heating and cooling load under a given condition.

In the area of water pumping system design and pump selection, the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. pipe sizes and fittings) on a water pumping system design and pump selection;
- Understand how to calculate the pressure drop across each individual component in a water pumping system;
- Understand how to appropriate size a water pumping system and select appropriate pumps based on the given design flow rate and system pressure drop calculations; and
- Compare the performance of a water pumping system under different design options.

In the area of air duct system design and fan selection, the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. duct sizes, materials and fittings) on an air duct system design and fan selection;
- Understand how to calculate the pressure drop across each individual component in an air duct system; and
- Understand how to appropriate size an air duct system and select appropriate fans based on the given design flow rate and system pressure drop calculations; and
- Compare the performance of an air duct system under different design options.

Mapping of graduate attributes to the Engineers Australia Stage 1 Competencies will be dependent on the manner and extent to which the *Deep Dive Case Study* is utilised. Preliminary mapping of competences against the perceived energy efficiency 'gap' attributes identified in 2012 Energy Efficiency in Engineering Briefing Note for participating in energy assessments and evaluating energy efficiency opportunities (Tables 1 and 2)[4] are provided below:

### Table 2.1 – Engineers Australia Stage 1 Competencies addressed by *Deep Dive Case Study*

| Selected perceived critical gaps (industry clustered themes) and mapping to EA Stage 1 Competencies[4] | EA Stage 1 Competencies[5] |
|---|---|
| Systems awareness, whole systems thinking, holistic approaches (Framing systems) | 1.1, 1.2, 1.5, 2.1, 2.2, 2.3, 3.1 |
| Collaboration, cross-disciplinary approaches, ability to work in a group | 3.5, 3.6 |
| Knowledge of measuring technologies and metrics, ability to identify inputs/outputs/losses | 1.2, 2.1 |
| Knowledge of energy principles, energy & relative amounts of energy needed for certain processes | 1.1 |
| Research skills | 2.1, 3.4 |
| Systems thinking - Identify all inputs and outputs, measurement and verification, create a baseline | 1.5 |
| Diagnostic skills, Critical thinking | 1.5, 2.2, 2.3 |
| Understanding of core engineering principles, including basic physics, thermodynamics and heat transfer, fluid mechanics, electrical machines | 1.1, 1.2 |
| Knowledge of EE technology | 1.1, 1.3, 1.4 |
| Financial education and evaluation skills, economic and business case analysis skills, ability to calculate expected Return on Investment (ROI) | 1.1, 1.3, 1.4 |
| Creative/ lateral thinking / Innovative thought processes, understand how and where to draw on external knowledge sources, capitalising on collaborative approaches/ team work | 2.1, 2.3, 2.6 |
| Reporting skills / documentations skills (potential opportunities, recording calculations) | 3.2, 3.3, 3.4 |

[4] 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.
[5] Stage 1 Competency Standard for Professional Engineer, Engineers Australia, available from http://www.engineersaustralia.org.au/, [date accessed March 2014].

## 2.5 Engineering sub-disciplines

The engineering disciplines included within this case study are the following:

- Civil
- Mechanical
- Process

# 3 Teaching guide

The *Deep Dive Case Study: Building Energy Use Analysis and System Design for Energy Efficiency and Sustainability* teaching resource is designed to be delivered as either a self-guided learning tool, tutorial task, workshop activity, or subject assignment.

The *Deep Dive Case Study* software allows the student to investigate and evaluate the impact of various design decisions in regards to commercial building energy efficiency and sustainability. The software aims to be able to provide an understanding of design outcomes due to parameter and material changes without having to laboriously perform a number of intermediate detailed calculations. To this regard it enables the user to establish a more holistic viewpoint of design outcomes in relation to energy efficiency and sustainability.

## 3.1 Pre-requisite knowledge

As indicated in Section 2.1, the resource incorporates three different levels of technical details, knowledge and skills. The resource may therefore be utilised for demonstration purposes, short tutorial problems, or detailed investigations. The resource however is not designed to be an introduction into the commercial building energy efficiency and sustainability topic area, and some previous knowledge of concepts related to commercial building operation and energy requirements is required to be delivered before implementation. Alternatively, the resource could be utilised in the later stages of sustainability related topics or later stages of the engineering degree program without introduction.

## 3.2 Embedding within existing programs

The *Deep Dive Case Study* is designed to be implemented at the practise and demonstrate phases of the undergraduate programme[6]. To this regard it is expected to be embedded into 3rd and 4th year subjects of the undergraduate degree programme. However, educators may wish to implement components during the learning phase of the respective engineering degree if used for demonstration purposes or guided tutorials, following introductory knowledge of commercial building operation and energy requirements.

An example task utilising the *Deep Dive Case Study* is provided in the *Companion Document*. The task is specifically designed for an initial high level of classroom discussion, followed by individual work or activity in small groups, and then reporting back to the larger group. This structure suits workshop styled tutorials. Initial high level discussion could be used to outline the scope of the activity (rather than it being provided). Detail in the task is left vague specifically to promote this purpose. The procedure of defining scope with a client, undertaking investigation and analysis, and reporting back

[6] C. Desha, *Energy Efficiency & Engineering Education: Increasing Energy Efficiency Knowledge & Skills*, Briefing Note for Engineering Practitioners and Educators, Report for Engineers Australia and DRET, 31 August 2012.

to the client, fulfils the requirement to emulate a typical energy efficiency related engineering problem.

## 3.3 Catering for different audiences

### 3.3.1 Varying class sizes

The *Deep Dive Case Study* software has been developed using Visual Basic and Microsoft Excel. The software has a reasonably large file size (10-15 MB) but is otherwise easily portable to individual computers or distributed via web based applications. Thus implementation into varying class sizes is only restricted by the number of computers accessible by the students.

### 3.3.2 Multi-disciplinary audiences

Use of the *Deep Dive Case Study* with multi-disciplinary audiences is encouraged and was part of the design brief during development. The detailed calculations within the software are based around building technology, civil, mechanical and process engineering. Depending on the relative experience of the students the detailed calculations may be analysed as part of the activity or omitted from the learning process (e.g. focus on lifecycle analysis). It is to be noted that the learning outcomes are focused towards engineering students specifically. Implementation beyond lower levels such as use as a demonstration tool to illustrate relationship between energy efficiency and material selection will require some knowledge of building physical elements to be established.

### 3.3.3 Dealing with multi-disciplinary audiences

For multi-disciplinary audiences, depending on the experience levels of students, the Level 1 and Level 2 stages of the *Deep Dive Case Study* are proposed to be most appropriate. Energy use analysis will be relevant to all disciplines to establish knowledge of the basic energy efficiency proposition. Tangible and effective measures to alter the energy use of the building provide a suitable discussion activity for all disciplines.