DEEP DIVE CASE STUDY 2:
Heavy Industry Electrical Energy Use and System Design for Energy Efficiency and Sustainability

Project EEERE:
Energy Efficiency Education Resources for Engineering

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:

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

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Companion Guide

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Produced by the University of Wollongong

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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 Overview

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 38% of Australia's total greenhouse gas emissions are a result of electrical energy production and industrial processes[3]. Reduction in electricity use across all sectors, including heavy industry, and an increase in cleaner energy production via renewables, is essential for a timely reduction in global energy related emissions and the promotion of environmental sustainability. Significant reduction in electricity use in industrial plants can be achieved through increased energy efficiency knowledge and implemented measures in electricity distribution and plant design.

This document is the Companion Guide to a *Deep Dive Case Study* analysing energy efficiency in heavy industry, focusing on electricity distribution and utilisation. This *Deep Dive Case Study* focuses on providing knowledge of energy efficiency management strategies and technological options for improving electrical energy utilisation. The case study provides an overview of energy use within a typical industrial plant, allows the student to develop an understanding of the energy loss mechanisms, and enables them to improve their understanding of the impact of design decisions and equipment selection on overall energy efficiency.

This *Deep Dive Case Study* will utilise a whole system approach to analysing a heavy industry plant and electrical distribution system in order to illustrate energy efficiency principals during the design process. The *Deep Dive Case Study* will provide the energy requirements for various mechanical and process loads, identifying how to reduce energy consumption and optimise the design of loads such as motor and lighting systems. It will also illustrate how to use life cycle cost analysis to determine the optimal system component rating and type, under the given design conditions, in order to achieve increased energy efficiency.

2 Benefits you will gain

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 energy use analysis and billing. Based on a base set of typical industrial loads and design conditions, the students can act as an engineering designer to estimate the energy use profile of an industrial plant including components such as lighting, air-conditioning, information technology, plant motors, etc. The students can also evaluate the impact of modifying time-of-use of equipment and understand the impact on overall energy use and peak load. This level allows for discussion on matching load to generation, including the impact of localised renewable generation, and the cost impact based on flat rate, time-of-use, or demand based energy charges.

Level 2 mainly focuses on the energy efficiency and life cycle costs associated with the design of the electrical supply system. This includes transformer selection, cable sizing and loss calculation, and lighting and motor type selection. Level 3 focuses on the estimation of energy savings, and impact on operating cost, for the application of a variable speed drive to a simple pumping system with variable flow rate requirements. Level 2 and Level 3 use a problem-based learning approach to highlight engineering considerations in the design of electrical and pumping systems and selection of equipment technologies.

[2] http://www.carbonneutral.com.au/climate-change/australian-emissions.html, accessed 10th December 2013
[3] Commonwealth of Australia, Quarterly Update of Australia's National Greenhouse Gas Inventory: March 2014, Department of Environment, http://www.environment.gov.au

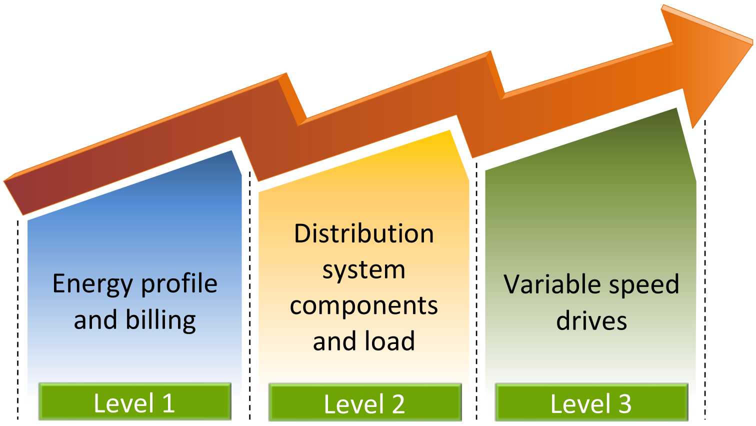

Figure 2.1 - Illustration of the three-level deep dive case study

Through utilising the case study at various levels you will develop a holistic understanding of the impact of various design decisions on heavy industry plant component energy use and gain knowledge of electrical distribution system and equipment design principles in general.

3 The case study task

You are to assume the role of a process or electrical design engineer. By analysing the scenarios available to you in the case study software, you are to evaluate the design options put to you in the design brief (Section 3.1) and provide suitable justification for your selected set of design parameters.

A range of scenarios below can be covered and tested in this case study in relation to heavy industry:

- Selection of plant loads and technologies to be included in plant energy profile including consideration of technologies to improve energy use at load/process.
- Electrical distribution design scenarios: meeting process and mechanical load requirements, layout design criteria for energy efficiency.
- Selection of individual electrical equipment components for energy efficiency: cable design; transformer design; lighting selection; and motor selection using whole system approach.
- Estimation of energy use based on system design, operational scenarios, loss mechanisms, and equipment selection; optimisation of design based on energy use.
- Variable speed drive application and calculation of energy savings; including dependency on voltage control, load cycle and load type.
- Use life-cycle cost analysis and design considerations to determine optimal variable speed drive design: equipment cost, installation and operational cost, lifecycle and energy savings.

The background details (assumptions, methodology and calculations) of each level of the case study software (refer to Figure 2.1) can be found in Section 5 to Section 7.

3.1 The design brief

As a process or electrical design engineer you are charged with the design and analysis of designing a plant using standard components and loads, e.g. distribution system components based on required rating, standard motor and lighting technology, etc. As a design engineer you also are to complete the design of the same plant utilising high efficiency components and loads and design methodologies aligning with energy efficient practises. You are to complete a full life cycle analysis of cost of ownership of each plant design, establish energy requirements and quantify emissions. You are to complete the activities outlined below related to the design of the plant. Assistance in defining the detailed scope of the task related to the two plant designs will be provided through workshop discussion.

3.1.1 Plant energy demand profile

By selecting all relevant loads and establishing their time of use, or duty cycle, develop a demand profile for each equipment type and establish the total plant demand. Analyse how the plant demand can be manipulated by altering processes in order to produce different plant profiles. By applying the available billing system options, determine which plant profile provides the least cost option for each billing type.

3.1.2 Design of plant electrical distribution system and load

For the plant equipment established in Level 1 spreadsheet, design a suitably rated electrical distribution system based on required ratings only. Establish the energy profile using standard equipment, e.g. use the least efficient motor and lighting systems. Determine an alternative design by selecting more energy efficient equipment technologies for motor and lighting, a more efficient power system transformer, and by optimising cable sizing for energy efficiency. Quantify the difference in up front, operational and life cycle costs of the more efficient plant.

3.1.3 Variable speed drive for plant pumping system

Given that a number of the motor systems in a heavy industrial plant will be related to pumping, assign a number of the motors in your demand profile from the Level 2 spreadsheet to be considered for variable speed drive applications. Assume that the assigned pumps are throttle controlled in the low efficiency plant design. Establish the life cycle cost benefit of making those throttle controlled pumping systems variable speed drive applications.

3.2 Task outcomes

On completing this task, you will have gained knowledge on energy usage analysis and energy efficient electrical design constraints for heavy industry plants, and established the impact of various energy efficiency design principles in general.

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

- Understand how each load contributes to create the total demand curve and how control of loads can bring down the peak demand value;
- Understand the effects of a range of variables and equipment selection options (e.g. ratings, system losses, duty cycle, time of use, etc.) on plant energy use; and
- Understand how to optimise the electrical distribution system design in order to reduce energy consumption and energy costs (including application of different tariff schemes).

Energy efficient electrical design:

- Understand the effects of a range of variables (e.g. duty cycle, peak demand) have on the design and selection of electrical distribution system components;
- Understand how to determine economic factors such as net present value and return on investment for justification of energy efficiency projects;
- Understand how to appropriately select power system components, e.g. transformer and cabling, in order to optimise design for energy efficiency and reduced life cycle costs; and

- Compare the performance of lighting and electrical motor system under different design options and energy efficiency retrofit applications.

In the area of variable speed drive design, the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. motor rating, process flow requirements, motor speed) on energy losses in a flow control process;
- Understand how to appropriately size pumping system components based on given design flow rate and system pressure drop calculations;
- Understand how to optimise control methods for energy efficiency;
- Compare energy losses of electronic variable speed drive controlled systems with valve controlled pumping systems; and
- Understand how variable speed drive applications enable energy efficiency improvements.

3.3 Task output

The deliverable output of this task is to be a summary report (limited to six pages) which details the considerations and design options outlined in the design brief. Specific outputs generated from case study calculations are to be included in the report to justify design parameter selections and/or verify impact of design alternatives (where applicable). Discussion and/or recommendations for optimal plant component and equipment design with respect to the low and high efficiency plant are to be included in the summary report. Include any external factors (beyond the case study software options) which you think would be important in regards to minimising plant energy use.

Where activities are undertaken in a group, the summary report must indicate the contributions from each member. Presentation of results will be required during tutorial discussion.

4 Software interface

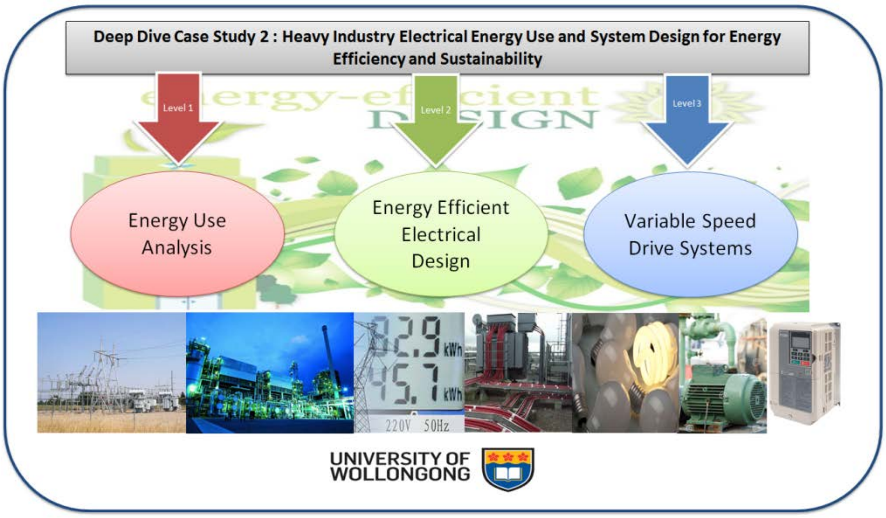

Figure 4.1 – Software home interface[4, 5, 6, 7, 8, 9, 10, 11]

[4] GLMV Architecture, http://www.glmv.com, *Background image*, [accessed June 2014]
[5] Crystal Electrical, http://www.crystalelectrical.com, *Substation image*, [accessed June 2014]
[6] ThyssenKrupp, http://www.thyssenkrupp.com, *Industrial plant image*, [accessed June 2014]
[7] Inhabitat.com, http://inhabitat.com , *Grid meter image*, [accessed June 2014]
[8] Scada Systems, http://elecdes.com, *Cable tray image*, [accessed June 2014]

As shown in the Figure 4.1 the software interface consists of three levels. You can click on the red, green or blue bubbles for each level to go into that particular level and work out the tasks allocated to each section.

In each level you will find different types of navigation buttons shown in the Figure 4.2 to assist you to perform various tasks.

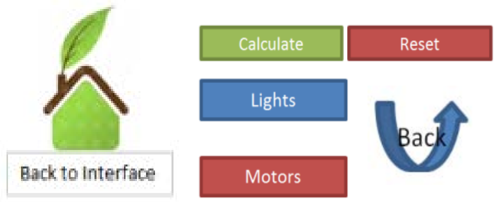

Figure 4.2 – Navigation buttons

5 Energy usage analysis

This section is focused on providing knowledge on how each load of a heavy industrial plant impacts on the overall electrical energy demand, how it contributes to the total annual energy usage, and how the time of operation impacts on plant peak demand. Users can study various demand curves related to the different types of loads and compare to the total demand curve. Also, this section provides an understanding of how the total demand curve changes when the usage percentage values (time-of-use and duty cycle) change during a day. Furthermore, in this section the user can understand how different types of tariff schemes work and establish how their selection impacts on overall operational costs.

The following default loads, listed below, are considered for the initial calculations. The user can manipulate all these load types and provide additional loads where required. The range of equipment loads are not limited, but may be introduced as part of the Deep Dive Case Study task.

- Lighting Loads 50 kVA
- HVAC loads 50 kVA
- Lifts 20 kVA
- Computer Loads 75 kVA
- Other Loads 50 kVA
- Motor loads 20, 2.2 kW

The power factor is assumed as 0.85 lagging for the non-resistive loads. The user can change the load values and the usage percentages as desired. These values are reused in the next level spreadsheet.

5.1 How to use the software

Step 1: The user can click "Calculate" (refer to Figure 5.1) to see the daily total electricity demand and the total cost per day utilising the default values assigned to each load type.

[9] Laser Electrical Lake Macquarie, http://lakemacquarie.laserelectrical.com.au, *Lighting image*, [accessed June 2014]
[10] Dreamstime, http://www.dreamstime.com, *Electric motor image*, [accessed June 2014]
[11] Yaskawa, http://www.designworldonline.com, *Variable speed drive image*, [accessed June 2014]

Step 2: The user can modify the ratings of each load type and the load profile by entering or modifying data in each of the spreadsheet columns.

Step 3: The user can click "Demand Curves" to compare the hourly demand curves related to each load and the how total demand curve varies during a particular day.

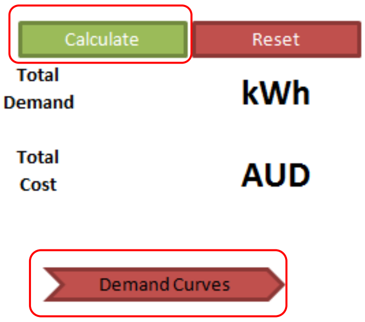

Figure 5.1 - Software user interface

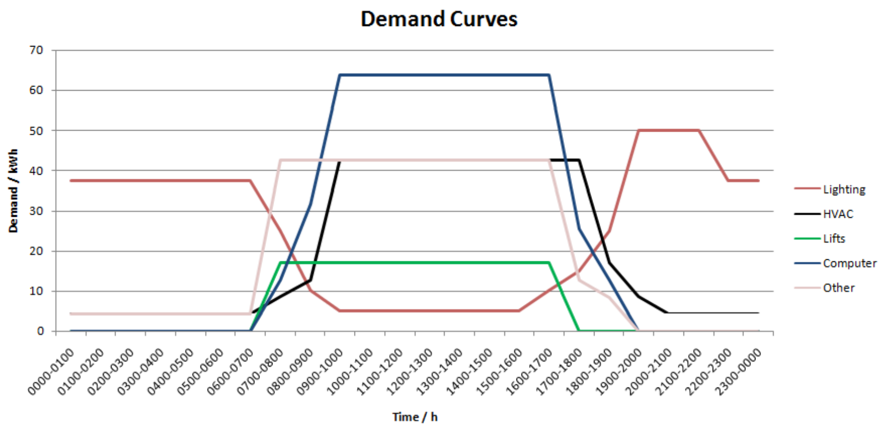

Figure 5.2 – Example individual load type demand curves

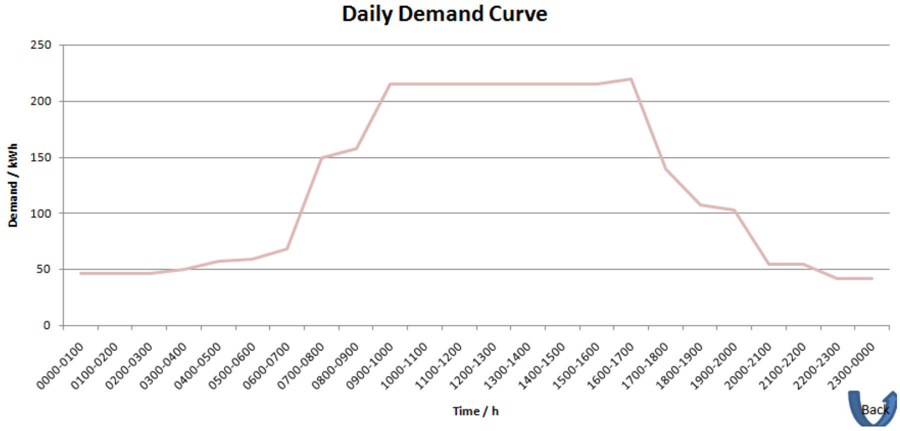

Figure 5.3 – Example total plant demand curve

Examples of the graphical output for the individual hourly energy load profiles and total hourly energy demand curve are illustrated in Figure 5.2 and Figure 5.3.

Step 4[12]: The user can change the tariff category from the drop down list provided by selecting “Flat rate”, “Time-of-use” or “Demand TOU” and then analyse how the total cost changes according to the tariff scheme (refer Figure 5.4).

For the “Flat rate” tariff scheme, the electrical energy price is fixed for every hour in the day and it is assumed to be $ 0.10 /kWh.

For the “Time-of-use” tariff scheme it is assumed that the energy price for peak time (between 1:00 pm – 8:00 pm) = $ 0.18 /kWh, for time shoulders (between 7.00 am – 1.00 pm and between 8.00 pm – 10.00 pm) = $ 0.12 /kWh and for off-peak (other) times = $ 0.05 /kWh.

Note: The above mentioned two tariff schemes are the typical to tariff schemes used for domestic users and small businesses. The following tariff scheme is typical of what is more widely used for industrial and commercial buildings.

The “Demand TOU” tariff scheme uses the same time periods as the “Time-of-use” tariff with different cost values, but an additional value is added to the cost based on the peak-demand value of kVA for a particular month, i.e. an additional cost of $ 16.00 is charged per kVA. For example, if the peak demand is 220 kVA and the total demand for the day is 2950 kWh,

Total = (2950 kWh x $ 0.21 /kWh) + (220 kVA x $16 /kVA) = $ 4139.50

Note: Most of the commercial and industrial users use load scheduling which allocate controllable loads to operate out of the peak-hours and to reduce the peak-demand. Try this by changing the usage percentage values in the Step 5.

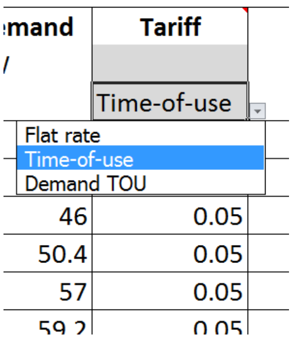

Figure 5.4 – Changing energy billing tariff scheme

Step 5: As the second stage of the Level 1 calculations, the user can change the usage percentages of each load and observe the changes of total demand curve and the total energy cost by following the Steps 1 to Step 4 as mentioned above.

[12] Endeavour Energy, http://www.endeavourenergy.com.au, Network Price List, [accessed June 2014]

Hours	Lighting	HVAC	Lifts	Computer Loads	Other Loads	Motor Loads
	50 kVA	50 kVA	20 kVA	75 kVA	50 kVA	44 kW
0000-0100	75	[illegible]	[illegible]	[illegible]	[illegible]	0
0100-0200	75	[illegible]	[illegible]	[illegible]	[illegible]	0
0200-0300	75	10	0	0	10	0
0300-0400	75	10	0	0	10	10
0400-0500	75	10	0	0	10	25
0500-0600	75	10	0	0	10	30
0600-0700	75	10	0	0	10	50
0700-0800	50	20	100	20	100	100

Enter usage percentage of each component during each hour.

Figure 5.5 – Changing load type demand profiles[13]

6 Energy efficient electrical design

In the Level 2 spreadsheet of the software, the user can gain knowledge on incorporating energy efficiency criteria into the design and selection of the major components of a heavy industry electrical distribution system. For this task, the theory of life cycle costing is used to identify the present values of the savings from the components of the system. Transformer, cables, lighting types and motors are considered as the default major components in the system. For each major component, detailed analysis is provided to assist the user in selection the optimal energy efficient components.

Data from the Level 1 (energy usage analysis) is used as the default values for this level, but may be altered as required to suit activities.

6.1 Transformer selection

For the energy efficient electrical design (Level 2) spreadsheet within the software the user can select a suitable rating for the distribution transformer based on system load, standard sizing or by optimising for energy efficiency. The desired loading of the distribution transformer is selected, a percentage value can be entered, and by clicking "Calculate" the total load data from the Level 1 spreadsheet is imported into the Level 2 spreadsheet and displayed accordingly. Refer to Figure 6.1. Then, by comparing with total load, the user can select an appropriate transformer rating (in kVA) from a drop down list.

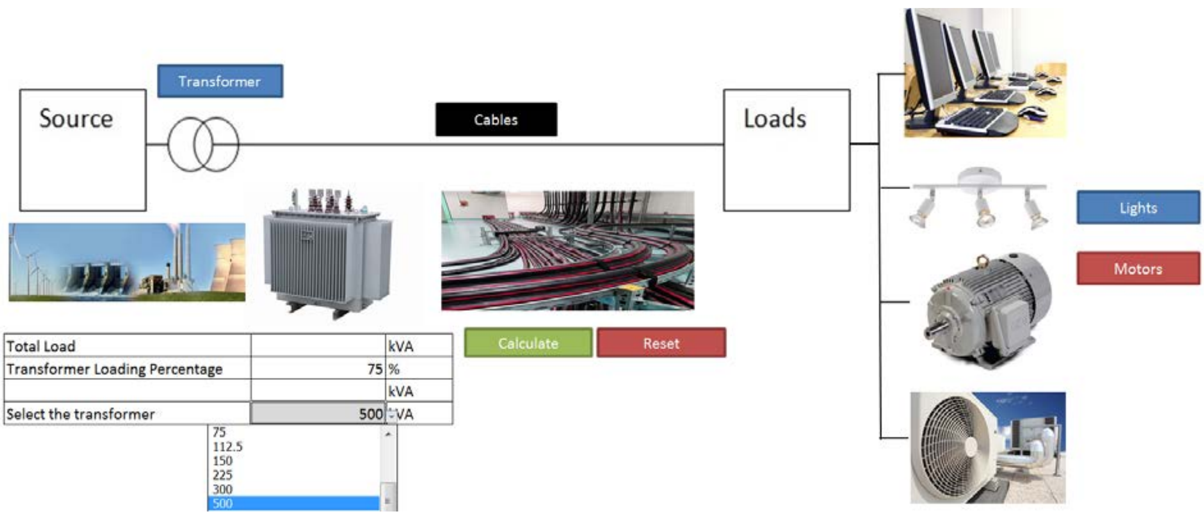

Figure 6.1 – Interfacing for Level 2 software platform[14, 15, 16, 17, 18, 19, 20]

[13] Aurora Energy, http://www.auroraenergy.com.au, *Digital meter image*, [accessed June 2014]

6.1.1 Transformer selection for energy efficiency

In this analysis, a standard transformer and a high efficient transformer are compared with their purchase value, load and no-load losses and derived values for the total owning costs and the relevant savings.

Step 1: Click "Calculate" to see the saving values.

Step 2: Change the loaded hours per year, life cycle of transformer (i.e. number of years), and determine how the transformer losses and total owning cost change for various scenarios.

	Transformer A Standard	Transformer B High Efficiency
Purchase price	10,194.00	10,845.00
No-load losses	1647	1100
Load losses at 100%	9507	7100
Load losses at selected value	5348	3808
PW	8.827119745	
Present Value of No Load Losses		
Present Value of Load Losses		
Total Owning Cost (TOC)		

Present Value of Savings	

Calculate Reset

Discount Factor %	7.5
No of Years	15
Electricity costs /kWh	0.21
Loaded hours per year	6000

Figure 6.2 – Interface for transformer comparison[21]

Calculations for transformer selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of costs and losses associated with transformer selection[22].

Total Owning Cost (TOC) = Purchase price
+ Present value of future no load losses
+ Present value of future load losses

No load losses per year = Transformer no load losses
x 8760 h/year
x Electricity cost/kWh
x PW

[14] Bentley, http://www.bentley.com, *Power generation image*, [accessed June 2014]
[15] All-Biz, http://www.in.all.biz, *Transformer image*, [accessed June 2014]
[16] Direct Industry, http://www.directindustry.com, *Cable image*, [accessed June 2014]
[17] Wix.com, http://www.wix.com, *Computer image*, [accessed June 2014]
[18] Homeposh.com, http://homeposh.com, *Light fixture image*, [accessed June 2014]
[19] AEM Group, http://www.aemgroup.net.au, *Electric motor image*, [accessed June 2014]
[20] ITP Business Publishing, http://www.constructionweekonline.com, HVAC equipment image, [accessed June 2014]
[21] Directorys.co, http://www.directorys.co, *Distribution transformer image*, [accessed June 2014]
[22] Sumper, A., Baggini, A., (2012), *Electrical Energy Efficiency: Technologies and Applications*, Wiley, pp. 40-44.

Load losses per year = Transformer load losses
x Loaded hours per year
x Electricity cost/kWh
x PW

Where,

$$PW = \frac{(1+i)^n - 1}{i(1+i)^n}$$

And, n = number of years (life cycle or project years), and i = discount factor.

6.2 Cable selection

Here, cable selection is focused on the cable from the transformer to the loads (e.g. emulating supply to and from the plant's main switch board). Design current is calculated based on the total load value of the Level 1. An optimal cable size is calculated given financial and electrical factors. This analysis covers the areas of voltage drop, short circuit current, and a cable comparison which is based on the loss cost and total cost per metre of cable.

6.2.1 Cable selection for energy efficiency

In this analysis, a design using standard cable sizing and a design considering energy efficiency parameters are completed.

Step 1: User can click "Calculate" to observe the value for "Optimal Cross Section" and selected cables accordingly for the cable comparisons with their voltage drop values.

Design current for the conductor	
Length of the cable m	

Discount Factor %	7.5
Electricity price	0.21
No of Years	10
No of hours loaded	3700
Loading percentage	70
PW	
F $/W	
Cable price per metre per sqmm	0.1

Calculate | Reset

Optimal Cross Section A mm2

Plot Chart

Voltage Drop Anlysis

Selected Cable sizes	300	400	500	630
Voltage Drop	0.185	0.166	0.15	0.138
Total voltage drop				

Total voltage drop should be less than 5% of feeder volatge

voltage drop of the selected cable	0.166
Maximum length of the cable / m	

Short Circuit Analysis

Short circuit current	
Minimum cable size to withstand for Isc	

(Assuming XLPE cable)

Cable Comparission

Cross section of the conductor	300	400	500	630
Current	420.64			
Price of the cable /m				
Loss cost /m				
Total				

Figure 6.3 – Cable selection interface[23]

Step 2: Click "Plot Chart" and observe the graph and see how lost cost and total cost of cables (per m) varies and select a suitable conductor size.

[23] All-Biz, http://www.in.all.biz, *Cable image*, [accessed June 2014]

Figure 6.4 – Cable cost variations

Optimal cable selection should be based on the lowest total cost where the red curve is a minimum. But in this case we have to use a cable which is larger than 300 mm^2 (cross sectional area). Therefore, optimal cable is 400 mm^2 for the parameters shown, i.e. needs to be larger.

Step 3: Insert the voltage drop value for the selected cable to see what the maximum cable length that can be used to maintain the voltage drop value.

6.2.2 Calculations for cable selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of costs and losses associated with cable selection[24].

Cross sectional area of cable, *A*

$$A = I_r \times 0.1433 \times (\frac{F}{C_c})^2$$

Where, I_r = Rated current in the circuit
C_c = Cable price per meter and per mm^2 cross section

$$F = (P_{loading})^2 \times t_{hours} \times T_{tariff} \times PW$$

Where, $P_{loading}$ = Cable load value, i.e. 75% = 0.75
t_{hours} = Number of hours cable loaded
T_{tariff} = Electricity cost ($/kWh)

Total cost of cable per meter length

$$C_T = (C_I + C_L)$$

$$C_T = (C_c \times A) + (\frac{1}{A} \times I_r^2 \times 0.02054 \times F)$$

Where, C_I = Cable investment cost
C_L = Cable loss cost

[24] De Wachter, B., Hulshorst, W., Di Stefano, R., (2011), *Cable conductor sizing for minimum life cycle cost*, European Copper Institute, Doc. Cu0105, Issue 1, July 2011.

6.3 Lighting selection

In this section, selection of lights is based on two different scenarios. First one is the new design which is derived from the basic parameters and is calculated the no of fixtures required from each different lamps. The second one is aimed towards a retrofit design where the number of fixtures is constant. In the retrofit design, lux levels before and after the retrofit is compared.

6.3.1 Lighting selection for energy efficiency

In this analysis, a design using various types of lighting technologies is considered in order to improve energy efficiency.

Step 1: Click "Calculate" to see the number of required fixtures required relevant to each lamp type for the design, energy cost per year for each type of luminaire. The user can change default data according to their designs.

Lighting Layout Calculator

Area to be lit/ m2	150
Desired Lux level	265
Average number of hours on per year	3000

	Luminar 1	Luminar 2
Watts per fixture	18	20
Number of lamps per fixture	2	2
Rated mean lumen per lamp	500	700
Ballast factor (BF)	1	1
Coefficient of Utilization (CU)	0.6	0.6

Electric cost per kilowatt hour AUD	0.21

No of fixtures required		
Total power load kW		
Energy cost per year		

Calculate

Reset

Consider a Retrofit Situation

Cost (including disposal cost)	80	60
Life in hours	10000	10000
Cost of labor to replace lamp	10	10

Cost per year

Figure 6.5 – Lighting design interface[25]

Step 2: Click "Consider a Retrofit Situation" to go to retrofit design. Click "Calculate" and check whether desired lux level can be achieved with new luminaire. Then user can click "Plot Chart" to analyse the graph of how lux level is changed due to the retrofit.

Area/ m2	150
Average number of hours on per year	3000

Compare Life Cycle Cost

	Luminar 1(New)	Luminar 2(Existing)
No of Fixtures		
Watts per fixture	18	20
Number of lamps per fixture	2	2
Rated mean lumen per lamp	500	700
Ballast factor (BF)	1	1
Coefficient of Utilization (CU)	0.6	0.6
Operating Cost Per Year		

Existing Lux Level with existing luminar	
Achieved Lux Level with new Luminar	

Calculate

Reset

Plot Chart

Figure 6.6 – Lighting retrofit design interface[26]

[25] Despoke, http://www.despoke.com, *Lighting image*, [accessed June 2014]
[26] Ledke Technology Co., http://www.ledke.com, *Lighting image*, [accessed June 2014]

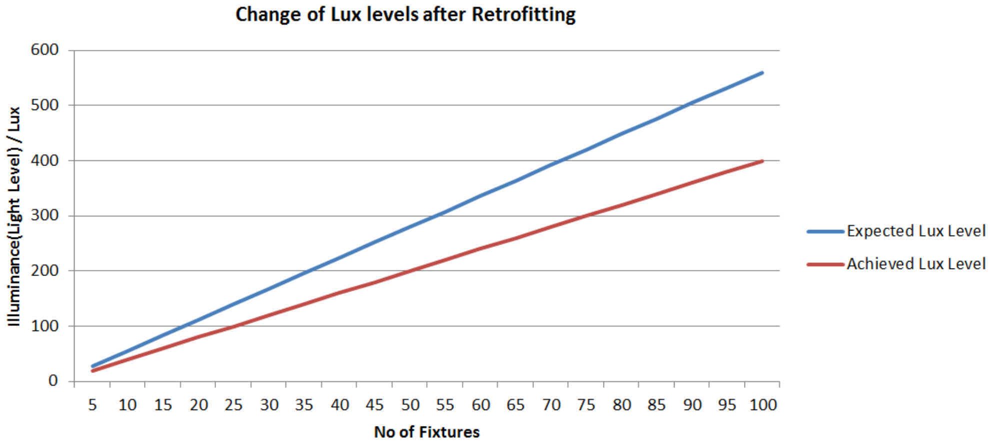

Figure 6.7 – Lux level variation with different luminaire

According to the graphs illustrated in Figure 6.7, even though the new luminaire saves operating costs, achievable lux level drops. Understanding the impact of energy efficiency measures on process output, in this case light, is vital if projects are to be realised effectively.

6.3.2 Calculations for luminaire selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of lux output, cost and losses associated with luminaire selection[27].

$$No\ of\ Fixtures = \frac{Area \times Desired\ Lux\ level}{No\ of\ Lamps\ per\ fixture \times Rated\ mean\ lumes\ per\ lamp \times BF \times CU}$$

Where, CU = Coefficient of utilization

BF = Ballast factor

6.4 Motor selection

This analysis is based on the total owning costs of a low efficient motor and a high efficient motor. In this section, user can identify the variations of motor operating costs with the motor efficiency and the total cost variations with the years.

6.4.1 Motor selection for energy efficiency

In this analysis, a design using various types of motor efficiencies is considered in order to improve overall plant energy efficiency.

Step 1: User can click "Calculate" to compare total owning costs, simple payback periods and operating costs of motors with different efficiencies. User can change the efficiency values and related motor cost to see how total owning cost changes.

[27] LightSearch.com, http://www.lightsearch.com, *Lighting guide*, [accessed June 2014]

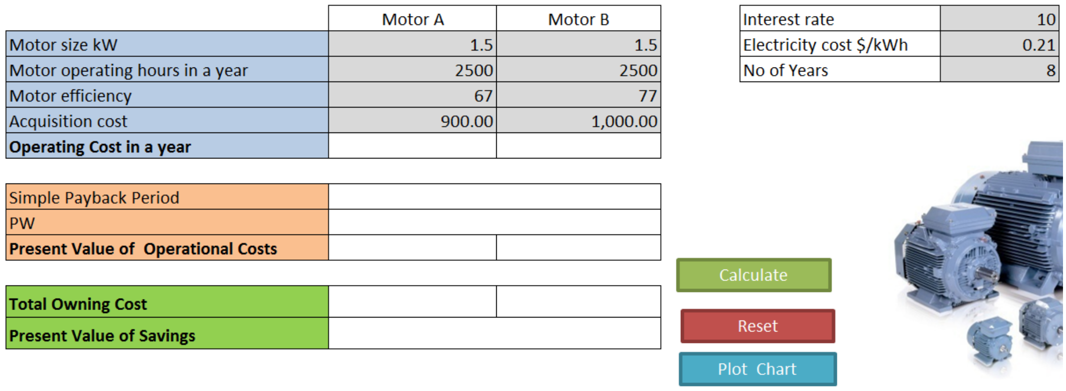

Figure 6.8 – Motor comparison interface[28]

Step 2: Click "Plot Chart" to observe the graphs. Following graph, Figure 6.9, shows how motor operating cost varies with the motor efficiency.

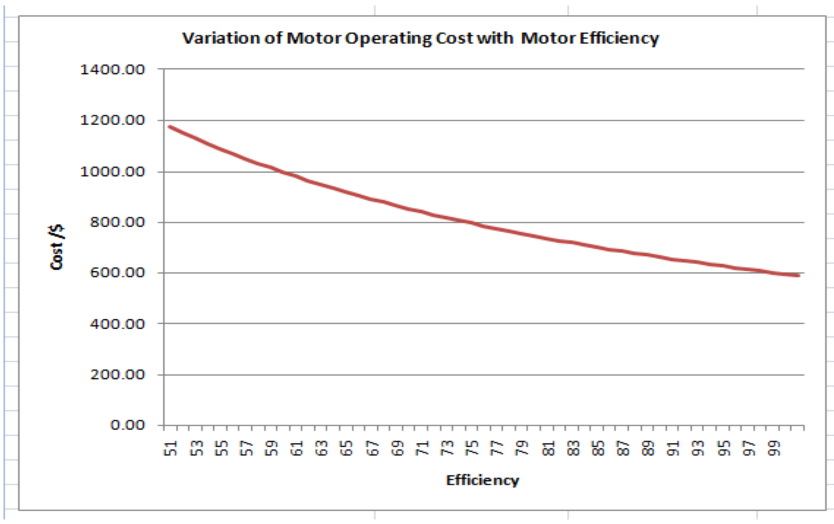

Figure 6.9 – Motor operating cost variation with efficiency

The next graph, Figure 6.10, provides an idea of how total costs of two motors with different efficiencies vary. Also, it shows how the total saving (if Motor B is used) increases with the years.

[28] ABB, http://catalog.wlimg.com/1/1501044/full-images/abb-electric-motors-988856.jpg, *Electric motor images*, [accessed June 2014]

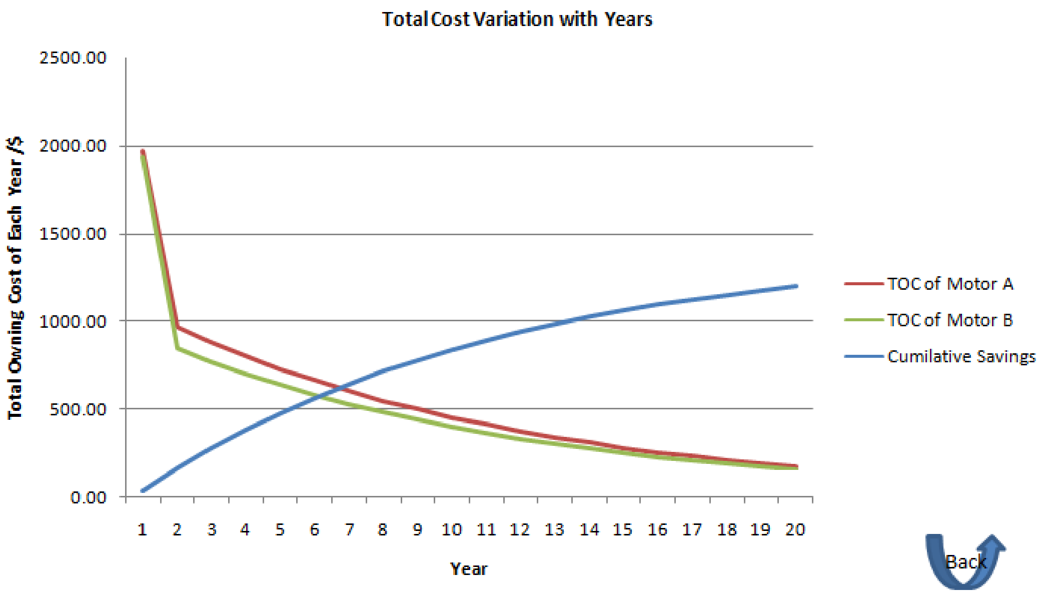

Figure 6.10 – Total cost variation with years for different efficient motors

6.4.2 Calculations for motor selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of motor operating cost and losses associated with motor selection[29].

$$Motor\ Operating\ Cost(MOC) = \frac{Motor\ operating\ hours\ \times\ Motor\ kW\ rating\ \times\ Electricity\ cost}{Motor\ efficiency}$$

Total Owning Cost = Motor acquisition cost + (Motor Operating Cost x PW)

7 Variable speed drive systems

In Level 3 of the *Deep Dive Case Study* software a variable speed drive system is considered. In this case it is used to drive a pumping system. The motor capacity is set at default value of 15.1 kW with an efficiency of 92%. This systems pumps water to a 32 m head with a flow rate of 125 m^3/h. The flow rate required for the example process is not constant throughout the day. It can be reduced by 25% of its initial value. If a throttle valve is used to adjust the flow rate, the motor runs with its full capacity, whereas a VSD system can reduce the motor speed in order to achieve the required flow rate.

This scenario is analysed to come up with values for energy savings when the VSD system is used.

7.1.1 Variable speed drives for energy efficiency

In this analysis, a design using variable speed drives for a pumping application is analysed in order to quantify the improvement in overall plant energy efficiency.

Step 1: The user can click “Calculate & Plot” to see the values of associated electricity cost of two different systems. Observation of the power consumption variations due to flow rate change by VSD system and a normal throttling valve system are reported via graphical means and in tabulated form.

[29] Dhillon, B.S., (2012), *Life Cycle Costing for Engineers*, CRC Press, pp. 124-125.

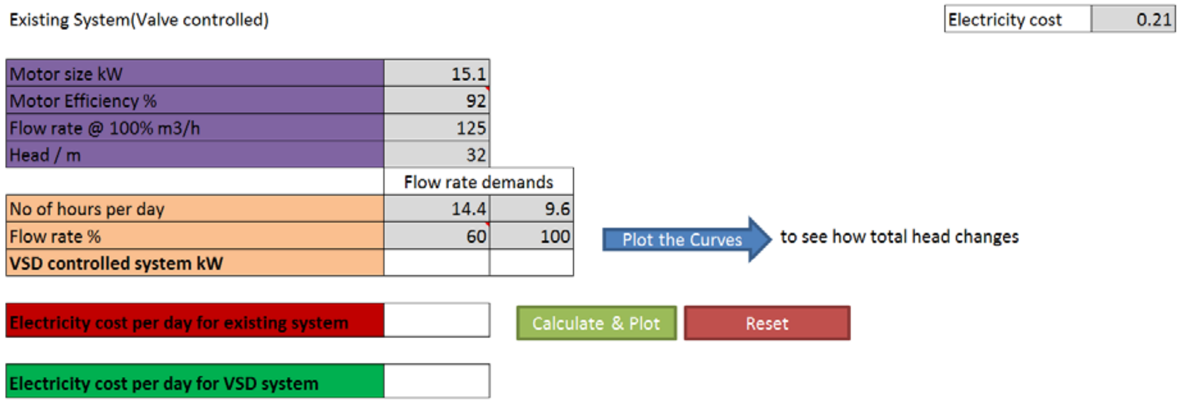

Figure 7.1 – Level 3 Variable Speed Drive Interface[30, 31, 32]

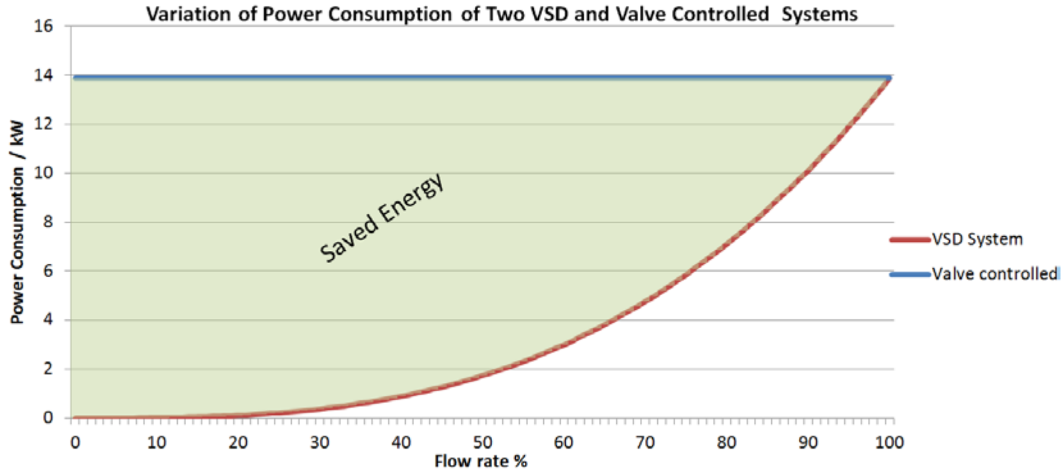

Figure 7.2 – Power consumption variation for two VSD and valve controlled systems

Step 2: Click "Plot the curves" to observe the variation of pump head when flow rate is changed by controlling speed using VSD.

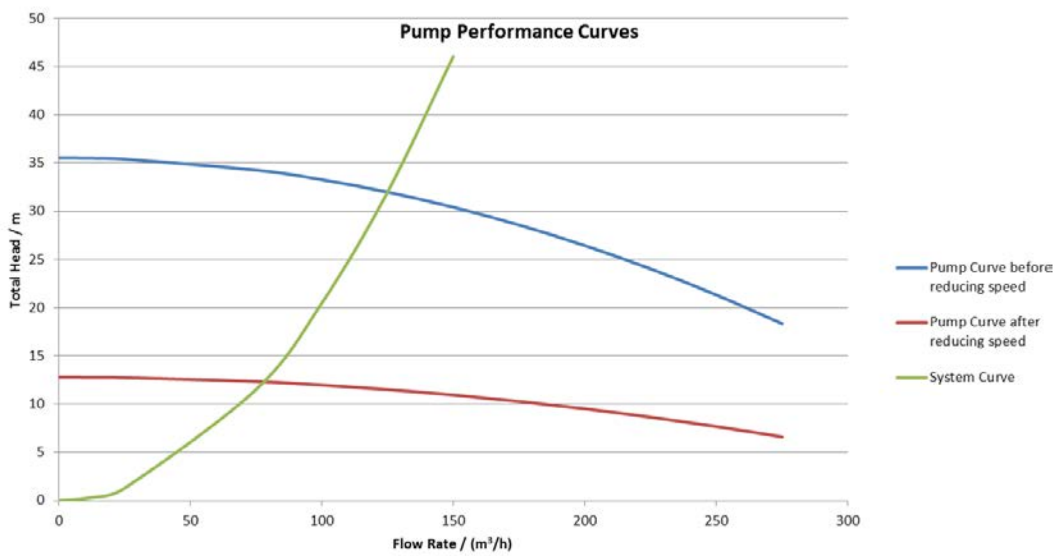

Figure 7.3 – Curve illustrating variation of pump performance

[30] Dreamstime, http://www.dreamstime.com, *Water valve image*, [accessed June 2014]
[31] Yaskawa, http://www.yaskawa.com, *Variable speed drive image*, [accessed June 2014]
[32] Star Motors Co., http://www.starmotor.cn, *Electrically driven pump image*, [accessed June 2014]

In this case, the pump curve changes due to the speed change from the VSD system. Initially, the pump has a flow rate of 125 m^3/h, while maintaining a 32 m head. However, due to the specific need of a 25% reduced flow rate, the VSD system changes the flow rate to a reduced value.

Step 3: The user can change the reduced flow rate value to a different value and see the variation by following the above step.

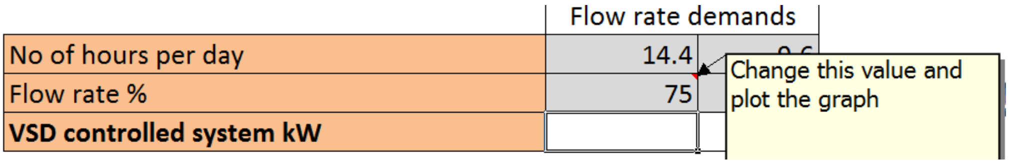

Figure 7.4 – Changing flow rate interface

7.1.2 Calculations for variable speed drive application

The following outlines the calculations embedded into the Level 3 spreadsheet for estimation of energy savings and energy efficiency associated with variable speed drive implementation[33].

Affinity laws used,

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = (\frac{N_1}{N_2})^2 \qquad \frac{P_1}{P_2} = (\frac{N_1}{N_2})^3$$

Where, Q = Volumetric flow (m^3/s)
H = Head (m)
P = Power (W)
N = Speed (rpm)

[33] Carbon Trust, (2011), *Variable Speed Drives: Introducing energy saving opportunities for business*, Technology Guide, CTC070, Available https://www.carbontrust.com, [accessed June 2014]

DEEP DIVE CASE STUDY 2:
Heavy Industry Electrical Energy Use and System Design for Energy Efficiency and Sustainability

Supporting Material

Project EEERE:
Energy **E**fficiency **E**ducation **R**esources for **E**ngineering

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:

Engineers Australia, aced, Australasian Association for Engineering Education, Energy Efficiency Council, asbec Australian Sustainable Built Environment Council

Australian Government
Department of Industry

Produced by the University of Wollongong

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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 38% of Australia's total greenhouse gas emissions are a result of electrical energy production and industrial processes[3]. Reduction in electricity use across all sectors, including heavy industry, and an increase in cleaner energy production via renewables, is essential for a timely reduction in global energy related emissions and the promotion of environmental sustainability. Significant reduction in electricity use in industrial plants can be achieved through increased energy efficiency knowledge and implemented measures in electricity distribution and plant design.

This document outlines a *Deep Dive Case Study* analysing energy efficiency in electricity distribution and utilisation in heavy industry. Based on provided or selected power system and load parameters (rating, type, time of use, etc.), the case study looks at energy use, electricity billing, distribution system equipment design, variable speed drive implementation, and the subsequent impact on energy efficiency. While the latter of these technologies are specific to electricity utilisation, 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 industrial plant energy use to identify possible technical options to reduce energy consumption, optimise the design of the electricity distribution systems and implement variable speed drives for water pumping systems. It will illustrate how to determine the optimal electrical system components (conductor, lighting type, variable speed drives, etc.) in order 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 10th December 2013
[3] Commonwealth of Australia, Quarterly Update of Australia's National Greenhouse Gas Inventory: March 2014, Department of Environment, http://www.environment.gov.au

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 energy use analysis and billing. Based on a base set of typical industrial loads and design conditions, the students can act as an engineering designer to estimate the energy use profile of an industrial plant including components such as lighting, air-conditioning, information technology, plant motors, etc. The students can also evaluate the impact of modifying time of use of equipment and understand the impact on overall energy use and peak load. This level allows for discussion on matching load to generation, including the impact of localised renewable generation, and the cost impact based on flat rate, time of use, or demand based energy charges.

Level 2 mainly focuses on the energy efficiency and life cycle costs associated with the design of the electrical supply system. This includes transformer selection, cable sizing and loss calculation, and lighting and motor type selection. Level 3 focuses on the estimation of energy savings, and impact on operating cost, for the application of a variable speed drive to a simple pumping system with variable flow rate requirements. Level 2 and Level 3 use a problem-based learning approach to highlighting engineering considerations in the design of electrical and pumping systems and selection of equipment technologies.

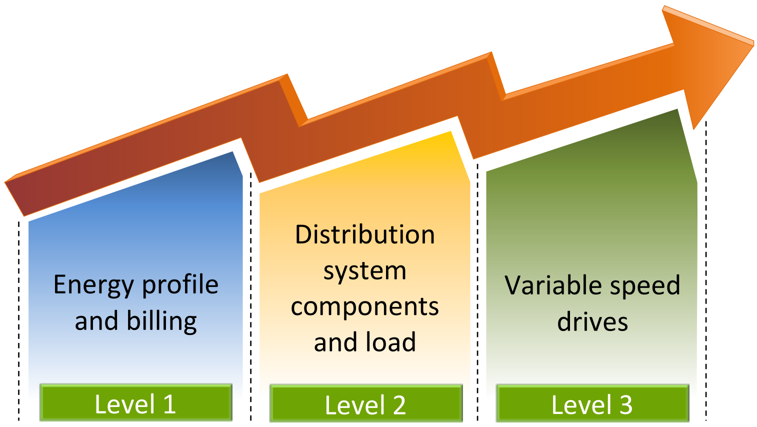

Figure 2.1 - Illustration of the three-level deep dive case study

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. Tasks can also be based on expanding or modify the spreadsheet calculations and methodology. The Microsoft Excel 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 load types in order to determine overall demand curves and impact on energy efficiency and operating costs;
- Adjusting the load types for the variable speed drive to analyse the potential energy savings achieved for each type; and
- Expanding the capabilities of the spreadsheet to integrate other energy efficiency options such as voltage conservation, etc.

Level 1 of the *Deep Dive Case Study* software is a single level worksheet and provides a general understanding of the impacts of load operation on plant energy usage profile including cost based on billing structure, impact on maximum demand and time of use schedules. The software is able to run simulation according to user defined inputs and provide results graphically in terms of total individual equipment and total plant energy demand profile. This part of the software is also designed to calculate total electrical energy and billing costs based on the design conditions which are subsequently used in the Level 2 spreadsheet, i.e. electrical system design.

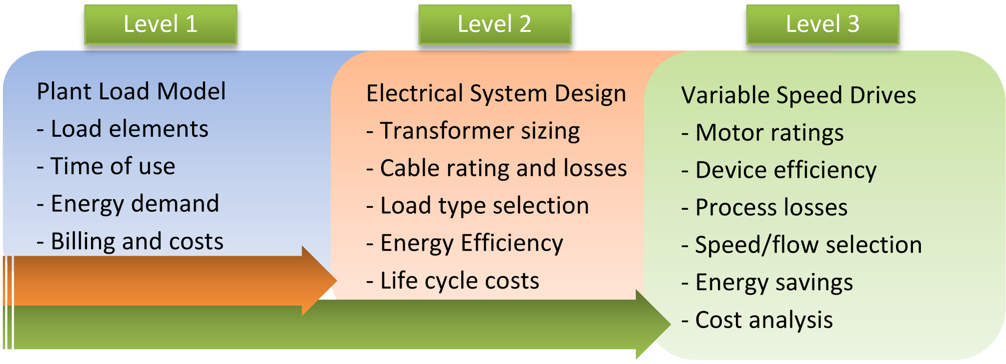

Figure 2.2 - Illustration of the three-level deep dive case study

Level 2 of the software enables the user to design and optimise the electrical distribution system components and load types for the *Deep Dive Case Study*. Transformer rating and efficiency can be altered to enable the user to understand the impact of losses and cost of ownership over the lifespan of the equipment. Cable system design and optimisation including consideration for energy losses and cost of ownership are determined based on user inputs and requirements based on standards. Selection of lighting based on output lux level, device selection and quantity, or comparison with retrofit of more energy efficient types is able to be analysed. User can also modify the parameters for motor load selection to assist with understanding the impact of implementing more efficient motor types.

Level 3 of the software analyses the energy savings possible from the implementation of a variable speed drive system to a pumping application. The variable speed drive design is achieved by first selecting suitable motor ratings, duty cycles, and process related pump flow rates (motor speed). The comparison of a variable speed drive system to simpler valve control is provided with the power consumption versus speed control graphical output provided by the software. Users can select different motor speeds to determine the best process design option based on energy savings and 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.

The Level 2 worksheet utilises data from Level 1 to ensure continuity of the *Deep Dive Case Study*. Future versions of the spreadsheet may enable Level 1 data to also carry through to Level 3 components. 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:

- Heavy industry
- Electricity distribution
- Electrical and mechanical design

2.3 Relevant technologies

The key technologies to be covered in the *Deep Dive Case Study* include electrical energy metering, electrical distribution system components (transformers, conductors), industrial loads (lighting, motors), and variable sped drive systems. A range of scenarios below can be covered and tested in this case study:

- Estimate the energy use of different industrial plant equipment and power system components based on given design conditions and selection of duty cycles (time of use);
- Analyse how modifications to the overall plant demand profile can allow for more optimal distribution system components. This can be achieved through enhancement of time or use or duty cycles of equipment of through using different energy efficiency technologies, e.g. lighting products and the inclusion of variable speed drives;
- Calculate the power versus speed characteristics of valve controlled and variable speed drive controlled processes, illustrating the margin of energy efficiency gains possible;
- Determine the optimal cable size and select the transformer by using life-cycle cost analysis; and
- Understand the implication of selection of electrical distribution system components and associated losses, and quantify the total cost of ownership of devices.

Visual display of system output 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 in Figure 2.3.

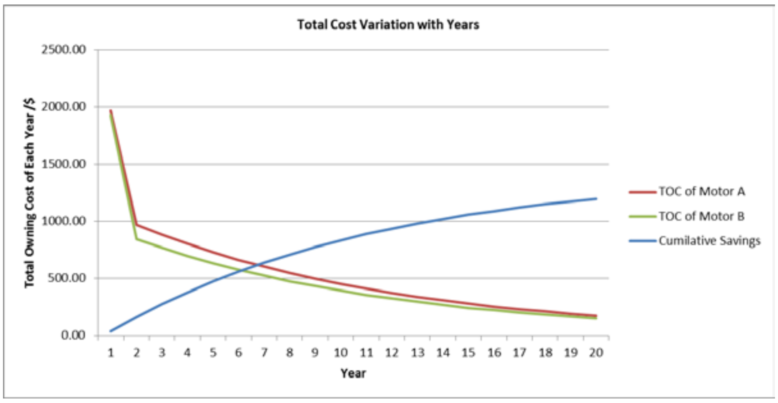

Figure 2.3 - Some information in the graphical interface of the sheet.

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 industrial distribution system losses and associated load energy use, and gain knowledge of energy efficiency principles in general.

In the area of heavy industry energy utilisation and efficiency the key learning activities are as follows:

- Understand the effects of a range of variables and equipment selection options (e.g. ratings, system losses, duty cycle and time of use, etc.) on plant energy use; and
- Understand how to optimise the electrical distribution system design in order to reduce energy consumption and energy costs;

In the area of heavy industry electrical distribution system components and loads the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. duty cycle, peak demand) have on the design and selection of electrical distribution system components;
- Understand how to determine economic factors such as net present value and return on investment for justification of energy efficiency projects;
- Understand how to appropriately selection power system components, e.g. transformer and cabling, in order to optimise design for energy efficiency and reduced life cycle costs; and
- Compare the performance of lighting and electrical motor system under different design options and energy efficiency retrofit applications.

In the area of variable speed drive design, the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. motor rating, process flow requirements, motor speed) on energy losses in a flow control process;
- Understand how to appropriately size pumping system components based on given design flow rate and system pressure drop calculations;
- Understand how to optimise control methods for energy efficiency;
- Compare energy losses of electronic variable speed drive controlled systems with valve controlled pumping systems; and
- Understand how variable speed drive applications enable energy efficiency improvements.

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:

- Electrical
- Mechatronic
- Mechanical
- Process

3 Teaching guide

The *Deep Dive Case Study: Heavy Industry Electrical Energy Use 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 electrical system energy efficiency and sustainability. The software aims to be able to provide an understanding of design outcomes due to parameter and equipment 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 heavy industry energy efficiency and sustainability topic area, and some previous knowledge of concepts related to electrical distribution systems and load 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 electrical system design and equipment 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 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 electrical, mechatronic, 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 equipment selection will require some knowledge of electrical distribution systems 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 selected plant equipment provide a suitable discussion activity for all disciplines.