Supporting Materials for Lecturers: Virtual Reality Experience

Grounding Students in Energy Efficiency Assessment Knowledge and Skills

Led by

Victoria University

Project EEERE:

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

Consortium Partners:

Project Partners:

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. 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).*

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 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.

Content

1. Introduction

Engineers have the potential to occupy an intellectual and social space that provides them with opportunities to shape, or even transform global society. A distinguishing feature of engineering is that it draws on a deep knowledge of science and mathematics. However, it is essential to complement these attributes with an ability to innovate and integrate ideas across a wide range of disciplines, and to communicate effectively with diverse audiences.

The Australian Government has recognised that many of these attributes of engineers can be harnessed to promote the efficient use of energy. Energy efficiency is considered to be a readily attainable and cost-effective method of reducing Australia's greenhouse gas emissions and reducing the costs energy consumption. However, if this policy is to be successful engineers must be able to:

- Think in terms of systems
- Communicate between and beyond engineering disciplines
- Develop a business case for energy efficiency opportunities.

The Virtual Reality Experience aims to achieve these objectives by inviting students to specify a virtual building, and as they modify aspects of its design they obtain instantaneous feedback on the

- Annual emissions of CO_2
- Amount of energy consumed annually by the building
- Annual cost of energy.

As noted in the Students' Guide[3] it is intended that students will gain tacit knowledge of factors that affect energy consumption in buildings. As a result, they will be able to form narratives that will enable them to 'communicate between and beyond engineering disciplines', i.e. with:

- Members of the public who are interested in energy conservation but who have not enjoyed the benefits of a science-based education.
- Fellow professionals in the building and construction industries, such as architects, accountants, building regulators and so on.

It is intended that students will appreciate that the factors that affect energy consumption are interdependent and this will satisfy our pedagogical aim that students must think in terms of systems. The Virtual Reality Experience software also provides users with an estimate of the running cost of each design which helps them to develop a business case for their designs.

Appendix I of this document presents details of the engineering science that guides the calculations of the heating and cooling loads associated with a commercial and industrial activity in a multipurpose building.

2. Statement of Coverage

2.1. Resource Focus

Energy consumption by buildings in Australia is responsible for over a quarter of the nation's greenhouse gas emissions. This is reflected in running costs incurred by the owners and occupiers of buildings. As reported in Thorpe et al[1], building design transcends traditional engineering in that it is intimately concerned with aesthetics, human comfort, economics, government regulations, environmental considerations and so on. As a result, building design involves a wide range of interested parties, often with conflicting interests. For example, a prospective building owner may wish to build an imposing and iconic building that is not particularly energy efficient. However, it must satisfy building regulations. There may also be a requirement that a distributed heating, ventilation and air conditioning system does not compromise the aesthetics of the building.

2.2. Relevant Industry Sectors

The Virtual Experience has been developed by a team comprising architects, practicing building engineers, professional software developers and an expert on pedagogy. This reflects its primary aim of educating people for the building sector in general, and environmentally sustainable design in particular. As noted above, the building sector employs over 10% of the nation's workforce, and the 'Virtual Experience' may be useful for instructing students in Vocation Education and Training.

The software enables students to explore how design decisions impact on the energy consumption of a commercial building that comprises office space. However, provision exists for the ground floor to house a café and a microbrewery. By making appr0priate design choices the operators of the microbrewery can reduce their energy consumption by over 70% and the amount of heat they reject into the factory space by over 80%. Students are able to make design decisions that realise these significant savings

2.3. Relevant Technologies

The principal technologies encompassed by the virtual software relate to:

- **Materials.** The 'Virtual Experience' will includes details of how insulation is used and installed in commercial buildings. Students can choose between three levels of insulation. The least effective is that found in existing stock of buildings, followed by insulation that satisfies minimum building standards laid down in the Building Code of Australia , and finally students are given the option of choosing better insulation and world's best practice.
- **Air conditioning systems.** The software highlights to students the availability of air conditioning systems that range from that found in existing stocks of buildings, through to those that satisfy the minimum requirements of the BCA through to world's best practice. The latter includes re-setting the condenser and chiller water temperatures to obtain maximum efficiency without compromising occupants' comfort. Further ways of improving the performance of HVAC systems is to install water pumps that have variable flow rates. This is potentially very effective because the power required for pumping increases as the approximately the third power of the volume flow rate.
- **Glazing.** Students will gain an appreciation of the effect that glazing has on the thermal performance of buildings. This will be complemented by users having the ability to investigate the effects of no shading or any combination of vertical and horizontal shading.

[1] Thorpe, G. R., Hocking, C., Kashuk, S., Linagre, D, Moller, S. and Pears, A. (2014) *Virtual Reality Experience - Supporting Materials* , a document produced by Victoria University for the Energy Efficiency Education Resources for Engineering (EEERE) Project, led by the Queensland University of Technology. An initiative of the Australian Government's Department of Industry, Canberra.

- **Lighting.** Seven percent of all energy-related CO_2 emissions[2] occur as a result of lighting. Hence, when people step into the virtual environment they will be able to determine the effect of the efficiency of the lighting system on energy consumption. Students will have the opportunity to study how technologies such as photo- and occupancy-sensors can reduce energy consumption by lighting. They will also have an opportunity to study the energy efficiencies and economics of compact fluorescent lamps and light emitting diodes that are about 4 and 7 times more efficient that incandescent lamps.

2.4. Engineering Sub-Disciplines

Energy conservation draws on a broad spectrum of engineering science. Some of the sub-disciplines involved in the 'Virtual Experience' are:

- **Heat transfer.** Heating and cooling loads on buildings are ultimately affected by the external temperature of the building envelope and other sources and sinks of heat such as solar radiation entering the building through windows and the infiltration of air. As a result, all three mechanisms of heat transfer are involved, namely conduction, convection and radiation. The interaction of these modes of heat transfer is evident when calculating the surface temperatures of the external surfaces of buildings. For example, the intensity of solar radiation on the exterior surface of a building can be calculated from the principles of solar geometry. The solar energy striking an opaque external wall of a building is generally absorbed or reflected. Some of the energy is convected to the atmosphere, some is conducted through the wall and thermal energy is also emitted to the sky and terrestrial surroundings. Solar energy may also be reflected from the surrounds before striking the building. The principles of engineering science may be applied to calculate the external temperature of buildings.
- **Engineering mathematics.** The equations that govern the temperatures external surfaces are highly non-linear. This project will provide students with examples of how engineering mathematics can be applied to solve practical problems of heat transfer in buildings.
- **Air conditioning engineering.** The 'Virtual Experience' provides students with the energy consumption of heating and cooling devices. This complements studies of the laws of thermodynamics.

[2] EIA (2009): Total Emissions from the Consumption of Energy. U.S. Energy Information Administration, online available: http://www.eia.doe.gov/emeu/international/carbondioxide.html, last access on 05/12/2014.

3. Teaching Guide - design of an energy-efficient commercial building

3.1. Pre-requisite knowledge

The Virtual Reality Experience enables students to select design features of commercial office buildings, and obtain instant feedback on the effects of their choices on energy consumption. The experience also includes estimations of energy consumption in a café/bar and a microbrewery that may be housed in the same building. The idea of including a microbrewery in the offering to the students arose because it employs several energy-intensive operations that are encountered in a number of industrial processes. However, as noted in the Introduction, a distinguishing feature of engineering is that it is built on a foundation of mathematics and science and the design of an energy efficient building rests ultimately on a creative application of these foundational principles. Hence, this resource highlights some of the engineering science that underpins the calculation of energy consumption in buildings.

3.2. Embedding within existing programs

One of the pedagogical motivations that informed the development of the resource is that it should highlight the need for competing ideas to be tested. For example, one student may assume the role of an idiosyncratic building owner, a second student might play the role of an architect whilst other students assume the roles of building services engineers and glazing specialists, say. The 'Virtual Reality Experience' has the potential to highlight the range and interlocking skills required to design a building. It also has the potential to highlight the decisive roles that engineering plays in societal issues. Exposure to these experiences will help to ensure that the students more job-ready.

The 'Virtual Reality Experience' consists of an architecturally rendered building, and students are able to select from the variables shown in Table 1.

Table 1. The design variables students are able to select in their 'Virtual Reality Experience'

Building Element	Design Variables
Walls	Lightweight Concrete
Insulation level of the walls	Poor insulation/current stock BCA Best practice
Windows	Three levels of glazing will be considered, namely: ➢ 0% of the wall area ➢ 30% - windows set into the walls ➢ 75% - aesthetically pleasing design
Windows – ground floor	The ground floor will include a glass door that will form part of the glazing. The glazing on the ground floor is likely to be different from the upper storeys.
Glazing and orientation	Provision will be made for each wall to be glazed differently. Each upper storey will have identical glazing and construction
Infiltration	Poor/existing stock BCA Best practice That region of the building used for an industrial process will make provision for a high degree of infiltration in case a roller door is installed for delivery and despatch of goods.
Shading	Provision will be made to shade each facade. It will take the following forms: ➢ No shading ➢ Vertical shading ➢ Horizontal shading

Building Element	Design Variables
	➢ A combination of vertical and horizontal shading
HVAC	Two systems, namely: ➢ Centralised ➢ Modular units Three levels of efficiency: ➢ Poor ➢ BCA ➢ Towards best practice
Lighting	Lighting to account for the type and quantity of glazing. Three lighting efficiencies: ➢ Typical existing systems ➢ BCA ➢ Towards best practice
Equipment	Energy consumption by typical office equipment will be accounted for. Three levels of power consumption of equipment will be accounted for, namely ➢ High output ➢ Medium output ➢ Low output Provision will be made to account for heat generated by an industrial process.
Hot water	Centralised systems Distributed system
Vertical transport	Single storey – no lift Double storey – slow lift Three storeys or more – fast lift
Operating schedule	50 hours per week – 8am until 6 pm five days per week.

These variables are selected from drop down menus. This Teachers' Guide is provided as a resource that deals with pedagogical outcomes of students participating in the Virtual Reality Experience. This Guide should be read in conjunction with the Students' Guide[3] that gives practical details of how to enter and obtain results from the Virtual Reality Experience.

3.3. Catering for different audiences

The Virtual Reality Experience has been designed for to be used by a wide range of audiences. This has been achieved by ensuring that it is easily accessible and user-friendly. It requires less skill to operate than a typical video game, yet it provides insights into factors that affect energy usage that are useful to:

- Engineers engaged in a wide range of disciplines, i.e. architectural, mechanical, electrical, lighting and so on.
- Architects who are required to quantify the effects of their design decisions on energy consumption.
- Builders who have similar requirements to those of architects.
- Members of the public who are interested in energy conservation when designing or proposing to occupy a building.
- Urban planners who wish to explore how energy-efficient communities might be established.

[3] Thorpe, G. R., Hocking, C., Kashuk, S., Linagre, D, Moller, S. and Pears, A. (2014) *Virtual Reality Experience - Students' Guide*, a document produced by Victoria University for the Energy Efficiency Education Resources for Engineering (EEERE) Project, led by the Queensland University of Technology. An initiative of the Australian Government's Department of Industry, Canberra.

The following steps highlight one opportunity for using this resource:

1. Provide students with the design brief outlined in the Students' Guide[3], namely they have to specify a commercial building in Melbourne or Brisbane. Students will then be asked to use their judgement to predict what will be the most important factors that are likely to impact on the energy consumption of their building.
   - The initial approach might be to consider each factor in isolation, i.e. the amount and type of glazing, the effect of shading and orientation and so on.
   - The above activities occur *prior* to the students entering the Virtuality Reality Experience.

2. After this introductory exercise they are asked to consider the interactions of the various design factors.
3. Students are then asked to pool their outcomes to identify what are the most important features of a commercial building with the internal use factors fixed.
4. Students are assigned to groups and they are introduced to the Virtual Reality Experience and each group investigates two design features in detail, and tease out any interactions between them.
5. Students are given free rein to manipulate factors that result in the minimum cost of the building. For this they will need access to capital costing that is not included in the Virtual Reality Experience - this is available as a cost guide[4] that students find interesting and constructive.
6. Students should be prepared to present their work in a variety of forms. One form could mimic that of a radio interview so that one student would be the interviewer and another student the interviewee. The challenge for both students is to make the interview interesting to imaginary radio audiences - the audiences might be supposed to represent two contrasting demographics that correspond to different radio stations.

3.4. Varying class sizes

A feature of the pedagogical software is that it has been designed so that it may be accessed on a very large scale. For example, on-line versions will be available. The supporting materials include tasks that are suitable for individual study or work in small groups.

3.5. Multi-disciplinary audiences

A strength of the 'Virtual Reality Experience' is that it is accessible to users with a great diversity of disciplinary backgrounds. An understanding of certain technical terms such as kilowatt-hours and tonnes of CO_2 is required, and these will be explained in terms that can be appreciated by lay people. As a result the work will be of benefit to a range of people engaged with sustainability issues. It may also be of interest to people with very little technical background as it will provide them with insights into technical issues that are involved in designing energy efficient buildings.

3.6. Online audiences

Comprehensive instructional material for on-line audiences will be produced as part of this project.

[4] Rawlinsons Construction Cost Guide, 2014, 32nd Edition, Rawlinsons Publishing, Rivervale, Australia

4.0 Supplementary teaching materials

The Virtual Reality Experience provides students with experience of specifying commercial buildings, and this will be expanded to incorporate the thermal performance of industrial buildings. However, as noted in the Introduction, a distinguishing feature of engineering is that it is built on a foundation of mathematics and science and the design of an energy efficient building rests ultimately on a creative application of these foundational principles. Hence, as part of this project a parallel guide will be produced for students that highlights some of the engineering science that underpins the calculation of energy consumption in buildings.

Appendix A includes details of the rationale of three energy usage scenarios that might be explored.

Appendix B comprises student notes.

Appendix A: Teacher Notes – Experience Development

Rationale for calculating the energy usage in a commercial and industrial activity carried out in the building, namely a café and a microbrewery

This Appendix provides information on the rationale underlying the models, as well as relevant data, data sources and algorithms

Overview

It is assumed that the micro-brewery occupies approximately 350 square metres, the cafe occupies approximately 400 square metres, and storage and 'back-of-house spaces for the brewery and cafe occupy 100 square metres. It is further assumed that the brewery and cafe operate 7 days per week, and that daily operation of the brewery and café are always the same. Patronage of the cafe varies over each day. Day to day variations have been ignored as they add a complication that may be pedagogically counterproductive. The facilities are considered to be 'all-electric' for simplicity and because many parts of Australia do not have access to low cost alternatives such as gas.

It is proposed that students will be able to specify several options for the ground floor usage:

- All office space
- Office + microbrewery
- Office + café
- Café + microbrewery

They will also be able to specify one of three efficiency scenarios for the microbrewery and/or café in addition to the existing options for the building envelope and internal energy use in the office.

The energy efficiency features and equipment for the scenarios are shown in Tables 1 and 2 below. Scenario 2 an example of using low cost measures, well-proven technology upgrades, and behavioural change. Scenario 3 is much more aggressive in adopting advanced low energy technologies, and it involves substantially more costly investment.

Brewery and café electricity and internally generated heat and 'coolth'

In preparing the virtual world, separate models of the energy flows for the café and brewery have been constructed. They estimate, for three scenarios each, the hourly and total daily electricity consumption, internal heat generated by equipment and (for the café, people), heat absorbed ('coolth') by cold vessels and equipment and net internal heat generated for each major element of equipment.

NOTE: all electricity use and heat flows are in kilowatt-hours: to convert to megajoules/hour multiply by 3.6.

The electricity data allow the program to calculate hourly, daily, weekly, and whatever other periods of energy use by activities other than heating and cooling that are required. It is assumed that ambient conditions do not influence the brewery process or café equipment energy use: this is an assumption that could be varied in a later version of the software.

Electricity prices and greenhouse intensity

For this version of the calculator, a single electricity price is proposed. Since hourly data are provided, it would be possible to apply time of use pricing or other pricing structures in a future version. Since relatively little electricity is used overnight, this will not make a significant difference to overall energy costs.

Electricity prices vary widely, but for small commercial/light industrial facilities such as these, a typical price in 2015 would be around 25 cents/kilowatt-hour. It would be useful if students were able to change the price and greenhouse intensity of the electricity.

Initially, the calculator is intended to apply to the Brisbane and Melbourne climatic zones. The latest values for greenhouse intensities of electricity in these two locations, as of mid-2013 are:

- Brisbane 0.95 kg CO_2 equivalent per kWh (this is the full-cycle value that includes power line losses and other impacts associated with delivery of the electricity to the meter. The Scope 2 emission factor is 0.82 kgCO_2e/kWh, as measured at the power station.
- Melbourne 1.32 kg CO_2e/kWh (scope 2 is 1.17 kg CO_2e/kWh).

Source: *Australian National Greenhouse Accounts: National Greenhouse Accounts Factors (July 2013)* Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education; this is available at www.climatechange.gov.au

The greenhouse intensity of electricity varies over time, depending on the mix of fuels used to generate it. The higher the proportion of renewable sources in the mix, the lower the greenhouse intensity. Businesses can buy certified Green Power by paying a slightly higher electricity price (usually around 5 cents/kWh extra), which is considered to be a zero emission electricity source under the National Carbon Offsets Standard.

Options for presenting information

The models are very detailed, and they contain too much detail to be used in the present version of the software. However, if it is required the more comprehensive data will be incorporated into more advanced versions of the software provided the financial resources are available for this next step.

Suggested reports

- Annual electricity use of the brewery equipment and separately brewery HVAC electricity use, and the same information for the cafe area and total facility.
- Annual cost and greenhouse gas emissions for the above (desirable if the values for electricity price and greenhouse gas intensity of electricity can be varied by the user – so they can evaluate low emission electricity options, Green power tariffs etc).
- Annual net amount of heat generated by the brewery equipment and net annual heat generated by equipment and people in the cafe, plus total facility.

Options for information for users, reports, activities

This Appendix provides a very brief overview of the brewing process and the roles of each item of equipment. This provides users with an outline of the brewing process and café activities, including names and roles of various items of equipment. I also provides some references on energy efficiency potential in brewing and cafes. Tables 1 and 2could be used to explain in broad terms what features are included in each of the three scenarios.

It is possible to provide breakdowns of electricity use, heat generation for selected major items of equipment, and hourly profiles of electricity use and net heat generation over a day. This could underpin discussion of the size and timing of peak electricity demand, and its potential cost implications under emerging electricity pricing structures. This would form an enhancement of the present software.

Students are able to carry out a variety of extension activities ‘offline’, such as:

- Investigating the capital costs of implementing the energy efficiency measures in the various scenarios and comparing them with savings and other potential benefits such as improved staff comfort, reduced peak electricity demand, reduced HVAC capacity requirements, etc
- Estimating the reductions in climate impact of the various scenarios
- Exploring the impact of the facility being stand-alone, or with commercial space on one or more floors above
- Exploring the impact of applying different efficiency scenarios to the brewery and cafe areas.

Algorithms

The algorithms could vary greatly in complexity, depending on the detail required for reports! However, equipment electricity use, cost and greenhouse gas emissions simply involve totalling electricity use for whatever categories and periods of time are desired, then multiplying them by an appropriate price or greenhouse intensity factor.

For this first version of the calculator, only annual results be shown.

- Annual kWh for each activity and efficiency scenario are shown in attached Tables. These can be shown separately or summed, depending on the level of detail required
- Annual greenhouse gas emissions in kilograms of CO_2 equivalent are calculated simply by multiplying annual kWh by the appropriate greenhouse intensity factor stated above.
- Annual amount of heat released into the building, which increases cooling energy requirements, while reducing heating energy use

Background information on the micro-brewery and café

This information is a brief summary of the brewing process, and activities in the café, as well as outlining the assumptions for each scenario.

The activities involved in this facility include:

- Café/Bar:
  - Lighting and HVAC (HVAC energy calculated by commercial building-energy software: this model provides hourly electricity consumption, heat generation (by equipment and people) and increase in outdoor air supply induced by exhaust fans)
  - Commercial refrigeration of beer and other drinks (cold room)
  - Display refrigerators for cold foods and drinks (9 self-contained units), post mix drinks unit (included in refrigeration)
  - Hot water supply for dish washing, sanitation etc
  - Office equipment, cash register, seating management system
  - Coffee machine, miscellaneous bar equipment (e.g. mixers, pumps), office equipment
  - Kitchen to prepare food (cooking, kitchen equipment), with exhaust fans for ventilation (the fans drive an increase in outdoor air inflow to the building)
  - The number of people in the café/bar is also stated, so that the amount of body heat released can be included in the heating and cooling calculations

- Brewing:
  - Brewhouse, where the following processes occur:
    - milling, mashing of grain
    - soaking of mash in the Lauter tun
    - Wort boiling, then filtration
    - Wort cooling
  - Fermentation in chilled tanks, where the fermentation process, storage and carbonation occur
  - Processing, where:
    - final filtration,
    - preparation of kegs and/or bottles, and filling,
    - pasteurisation (if required – not at this site)
    - and final labelling and packing (if required) occur
  - Beer may be stored prior to distribution

Micro-brewery

The main processes in brewing include:

Milling and mashing the grain into grist in a milling machine. Such machines take several forms, one of which is depicted in Figure 1.

Figure 1. A milling machine typical of that found in in a microbrewery.

The grist is then mixed with hot water and fed into the mash tun (Lauter Tun), where mash is soaked in hot water (70-80°C) and filtered before the liquor enters the hot liquor vessel. The mash tun sits above the hot liquor vessel which collects the hot wort (liquid with all the 'goodies' extracted from the grain or grist)

The hot liquor is then pumped to the wort kettle where the filtered hot liquor is boiled for 1-1.5 hours.

Figure 2. Wort kettles

Figure 3. Fermentation vessels

- After fermenting, the beer is placed in a cold liquor tank where the fermented product is stored and kept cool for between a few days to a month before filtering and storing in conditioning tanks.
- After carbonation and final filtering, the beer is packed into kegs at our model microbrewery. In many breweries, beer is pasteurised (usually by heating it to around 65C) before packaging.

Figure 4. Cold liquor tank

The microbrewery in this calculator is loosely based on a detailed energy analysis of a microbrewery by Nadia McPherson of Newcastle University, which provides real data on which to base the model. The presentation is not dated but seems to be around 2010.

This brewery produces 56,000 litres of beer per month in a well insulated building in UK, with a floor plan as shown below. The Brew Hall is 90 square metres (approx. 6.7 by 13.5 metres). The total area occupied is approximately 350 square metres. Production would be about 2,000 litres/day, consistent with a successful business that also supplies several other outlets. It is assumed that sales to other outlets is in kegs, rather than bottles, to simplify the process requirements.

Based on assumed seven day per week operation, the microbrewery's annual energy use for the three scenarios considered is shown in Table I.

Table II shows the amounts of heat generated and released or absorbed by the brewing processes into the conditioned areas of the brewery. Note that the reductions in heat released differ from the electricity savings, as some heat is released into unconditioned areas, and changes in process energy can differ from changes in amounts of heat released.

Table I. The annual energy usage of the microbrewery.

BREWERY	**Base**	**Mod**	**Strong**
ELECTRICITY kWh	annual	annual	annual
kilowatt-hours			
security/base lhts	8213	5338	2464
indoor lighting	17520	8760	3504
office equipment	4380	4380	1314
kitchenette	2373	2373	1424
general space conditiong	calculated by building calculator		
HWS/boiler	160600	125195	51611
pipes	17520	7008	2803
cold rm cool	30660	24528	6015
wort chill	9581	7665	3066
cool ferment	7008	5606	2243
TOTAL	257854	190853	74443
Percentage saving (electricity)		26	71

Table II. The amounts of heat generated and released or absorbed by the brewing processes

HEAT FLOWS (kWh thermal)	**Base**	**Mod**	**Strong**
Heat generated	annual	annual	annual
security/base lighting	2738	1369	548
lights	17520	8760	3504
cleaning (HW, equipt, kegs)	91250	63875	14600
heat from mash tank	274	274	192
heat from wort heat-up	730	730	511
heat from wort boil	22995	22995	11498
heat as wort chilled	146	146	146
motors, pumps	7483	5986	2993
heat from HWS/boiler	10950	2924	2924
pipes	17520	7008	7008
heat hourly total	171605	114066	43922
Heat removed			
cold rm cool	15330	12264	12264
wort chill	4791	4791	3833
cool ferment	3504	3504	3504
hourly total coolth added	23625	20559	19601
NET HEAT generated	147980	93508	24322
Percentage reduction (net heat into spaces)		37	84

The layout of the microbrewery on which the model is based is shown below, and includes the following:

Cold room:

- Conditioning tanks, kept cool for a few days to a month;
- Cold Liquor Tank where fermented product is put before filtering and storing in conditioning tanks

Brew Halls 1 and 2:

- FV=fermenting vessel, kept at 6-25°C, depending on type of beer, where yeast is added and fermentation occurs over 3 to 10 days, depending on type of beer. (NOTE: brew hall 1 is hot from heat losses from other processes!)
- Mash Tun where mash is soaked in hot water (70-80°C) and filtered before it goes to:
- HLT=Hot Liquor Tank (Lauter Tun), from where it is fed into the Wort Boiler
- Copper Tank (Wort Boiler) where the filtered hot liquor is boiled for 1-1.5 hours

Boiler house where boiler and water feed tank are located.

Note that the doorway between cold room and brew house 1 allows large amounts of heat to enter the cold room. Ancillary equipment such as chillers, space heaters and coolers, pumps etc not shown.

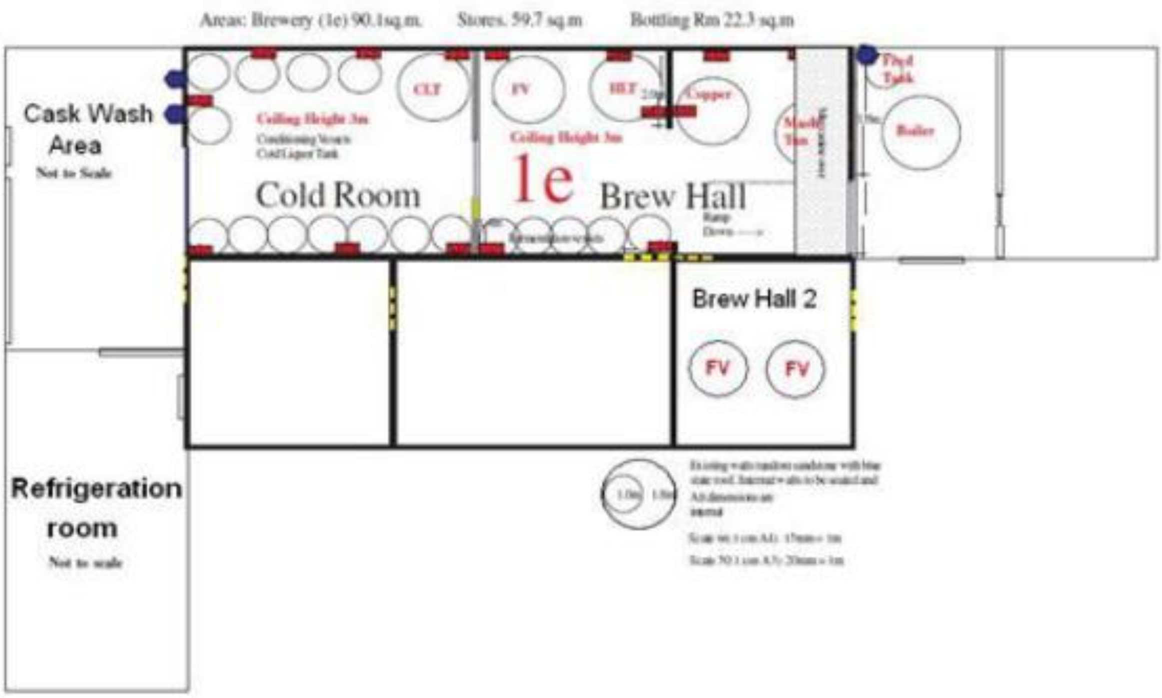

Figure 5. Layout for the model

Figure 5 (above) is the basis for the model, but it has been adapted using a variety of data sources.

TABLE III: Details of Micro-brewery energy scenarios (see later for Café/bar):

ACTIVITY	SCENARIO 1: BASE CASE	SCENARIO 2: MODERATE SAVINGS	SCENARIO 3: HIGH SAVINGS
Lighting – indoor and outdoor	Outdoor lighting: inefficient mercury vapour lamps Indoor: 20 year old fluorescent tubes and fittings	Metal halide lamps, better reflectors 35% saving Modern T5 fluorescent lamps with reflective fittings: 50% saving	LED lamps with movement and daylight sensors: 70% saving LED lamps with smart dimming and daylight sensors, increased use of daylight: 80% saving
Office equipment and kitchenette	Standard desktop computer, printer, fax and copier. Kettle, old fridge, microwave oven, toaster	No change	Laptop computer with LED screen, multi-purpose printer/fax/copier/scanner; Efficient fridge: 60% saving
Wort tank	Standard	No change	Insulation improved so heat flow reduced by 20%
Hot water/boiler	Resistive electric with large storage tank	Improve insulation: 5% saving. (note further savings due to reduced hot water for cleaning)	S2+ Heat pump HWS topped up by resistive heating boost for wort: 60% saving (note further savings due to reduced hot water for cleaning and wort heat recovery also included here)
Pipes (heat and cooling)	Low levels of insulation, with gaps	Upgrade insulation: 60% saving	As for scenario 2
Cooling and chilling	Standard equipment	Reduce ambient temperature of surroundings by isolating from hot areas, improve maintenance: 20% saving	S2+ High efficiency chiller, upgraded cool room and tank insulation: saving 60%
Motors and pumps (included in equipment energy use)	Fixed speed motors with valves to control flows, limited maintenance	Variable speed drives fitted to motors: saving 20%	S2+ plus high efficiency motors and pumps, smart controls and improved maintenance: saving 60%
Cleaning with hot water	Extensive use of hot water to clean equipment and surfaces	Water-efficient hose fittings: saving 30%	S2+user-controlled flow, revised practices to optimise cleaner behaviour: saving 60%
Electricity saving from Scenario 1	**Base case**	**26%**	**71%**

Café/Bar

Cafes and bars typically have very poor energy efficiency. Almost every aspect of energy use can be dramatically improved in efficiency. For example, refrigeration equipment typically has limited insulation, low efficiency compressors and inefficient internal lighting. Cooking and food display equipment is also typically very inefficient and, in many cases, management of this equipment is poor as hotplates are left on in case they are needed, and insulation is poorly designed. High standby power use is common, for example a typical coffee machine uses 300 watts on standby.

Overview

The café/bar occupies around 400 square metres of ground floor area, of which 50 square metres is ‘back-of-house’ unconditioned area in which a coldroom, electric HWS units and ambient temperature storage space for supplies are located. A commercial kitchen area, where food is prepared and cooked, forms part of the conditioned space (behind the serving benches). Nine glass-door refrigerators are installed for display and storage of drinks and food items.

A mixture of ‘mood lighting’ and fluorescent lights is installed.

The facility sells a range of beers, particularly beer produced on-site in the attached micro-brewery, a variety of other alcoholic and non-alcoholic drinks including coffee and tea, and a variety of cooked food and meals and take-away food.

It operates seven days per week from 7am to 11pm, offering breakfast, lunch, dinner and ‘grazing’ food options.

The dining area is a conditioned space. Whilst it would be desirable to allow for an option of opening up one wall to create an ‘indoor-outdoor’ space, this would be difficult to model, so it is proposed to leave this for a future software upgrade. Provision can be made for an outdoor dining area but, for simplicity, it would not be heated in this model. [We could add a simple option where a separate option allows electric heating to be used for specified hours and parts of the year.] Electricity usage for the three scenarios is shown in Table IV.

Table IV. Electricity usage for the three scenarios

ELECTRICITY kWh	**Base efficiency**	**Moderate efficiency**	**Strong efficiency**
	annual	**annual**	**annual**
	5738	3730	1721
Lighting	42486	16994	8497
refrigeration	58805	41163	23522
sanitation (HW?)	50381	40305	12595
food preparation	159336	127469	79668
IT equipment	4964	3475	1986
cooling	calculated by building calculator		
heating	calculated by building calculator		
ventilation	7957	6366	3183
other - fans, coffee etc	9986	9110	6018
TOTAL ELECT	339653	248612	137190
Percentage saving	-	27	60

Table V. Total energy usage for each of the three scenarios

HEAT kWh thermal	Base efficiency	Moderate efficiency	Strong efficiency
	annual	annual	annual
external lighting/signs	0	0	0
lighting	42486	16994	8497
refrigeration	43333	30333	17333
sanitation (HW)	25190	20152	6298
food preparation	55768	44614	38530
IT equipment	4964	3475	1986
cooling	calculated by building calculator		
heating	calculated by building calculator		
ventilation	2263	1810	905
other - fans, coffee etc	9986	9110	6018
TOTAL HEAT	**183990**	**126489**	**79567**
Percentage saving	-	31	57

Heat generated within conditioned space differs from the amount of electricity used, as some activities contribute less heat, as discussed below:

- indoor lighting, signage 116 kWh/day (It is assumed that outdoor lighting does not contribute, but all electricity used for indoor lighting is converted to heat within the building)
- Refrigeration: cold room, display refrigerators 119 kWh/day. (It is assumed that the cold room compressor is outside, and that only 25% of the heat flowing into the cold room comes from walls shared with conditioned spaces, so it has small a net cooling impact on the café) – this is equivalent to 0.5 times the electricity consumed, as twice as much heat is extracted as electricity used, so it is 0.25 of 2 times the electricity.
- Hot water and dishwashing 69 kWh/day (It is assumed that 50% of the energy for heating water used is not released into the conditioned space, but is lost with water flowing down effluent pipes and from storage tank heat loss not within conditioned spaces).
- Office equipment 14 kWh/day (It is assumed that all energy from equipment is converted to heat released in the conditioned spaces)
- Catering equipment: coffee machine and miscellaneous equipment 27 kWh/day (It is assumed that all energy from equipment is converted to heat released in conditioned spaces)
- Cooking and food preparation 153 kWh/day (It is assumed that 65% of heat from cooking is removed by the exhaust fans)
- Exhaust fans and ventilation 22 kWh/day (It is assumed that 70% of the air removed by the exhaust fans has been supplied by a 'make-up' air inlet or from a nearby window or door open to ambient conditions rather than being drawn from the conditioned space: this is probably optimistic for the base case!)

The main features of the three scenarios are listed in Table VI below.

Table VI. The main features of the three energy consuming scenarios

ACTIVITY	SCENARIO 1: BASE CASE	SCENARIO 2: MODERATE SAVINGS	SCENARIO 3: HIGH SAVINGS
Lighting – indoor and outdoor	Outdoor lighting: inefficient mercury vapour lamps and neon signage Indoor: mix of halogen and fluorescent lamps with lighting intensity 15 watts/sqm	Metal halide lamps, better reflectors, LED signage: 35% saving Modern LED and T5 fluorescent lamps with reflective fittings: 60% saving	LED lamps and signage with movement and daylight sensors: 70% saving LED lamps with smart dimming and daylight sensors, increased use of daylight: 80% saving
Commercial refrigeration (coldroom)	COP=2, 25% of 'coolth' leaks into conditioned spaces	Improved coldroom insulation, plastic strips to limit air leakage when door is open: 30% saving	High efficiency compressor and heat exchangers, advanced insulation to avoid thermal bridges, smart door management: 60% saving
Display refrigerators	9 stand-alone display units (glass doors) with built-in compressors, average efficiency and a post-mix chiller for 'on tap' drinks	Moderate efficiency improvement using more efficient compressor, reduced thermal bridging: 30% saving	High efficiency with improved door performance, high efficiency smart LED lighting: 60% saving
Hot water and dishwashers	Several resistive electric HWS units, half of them inside the conditioned space, used for cleaning, dish washing and miscellaneous activities	Water-efficient taps, sprays, dishwasher, storage tank insulation improved, improved training of staff to minimise hot water waste: 20% saving	Heat pump HWS units installed: 75% saving on water heating energy. Further improvement in efficiency of hot water usage so that heat into conditioned space from hot water use is halved.
Office equipment	Standard desktop computer, cash register and seating management system, printer, fax and copier.	Upgrade to modern equipment: 30% saving	Laptop computer with LED screen, multi-purpose printer/fax/copier/scanner, low standby electronics: 60% saving
Ventilation fan energy	Exhaust fans over cooking equipment, fixed speed units with standard grease filters, standard efficiency motors and fan design	Filters cleaned more often, high efficiency fan/motor units: saving 20%	Variable speed drives on fans, controls automatic, linked to cooking activity/ exhaust air temperature, redesign of ducts to cut pressure drop: saving 60%
Coffee machine and misc bar and serving equipment	Standard	Coffee machine and other equipment switched off outside operating hours: small overall saving outside working hours: approx. 10% saving	High efficiency coffee machine (insulated components, low thermal inertia components, low standby power) and other equipment: 40% saving
Cooking and food preparation equipment	Resistive electric cooking equipment, warming ovens, microwave oven, exhaust fans	Improved management of cooking equipment, including lids on chip fryers and pots, equipment switched off when not needed: 20% saving	Induction cooking replaces resistive electric equipment, high efficiency ovens with heat recovery so exhaust air pre-heats inlet air, upgraded insulation on all cooking equipment: 50% saving
Electricity saving from Scenario 1	Base case	Approx. 27%	60%

Appendix B: Student Notes – Two Tasks

Virtual Experience Task 1: Designing an energy-efficient commercial building

1.0 Overview

Energy consumption by buildings in Australia is responsible for over a quarter of the nation's greenhouse gas emissions. This is reflected in running costs incurred by the owners and occupiers of buildings.

The energy consumed by existing buildings can be reduced, sometimes by taking simple measures such as installing more efficient lighting systems, or by choosing slightly different settings of thermostats. As we might expect, more opportunities to improve the energy efficiency of buildings present themselves at the design stage. For example, it may be possible to improve the thermal effectiveness of buildings by specifying an appropriate type of glazing materials that is applied to the exterior of a building envelope. Designers can also specify efficient heating, ventilation and air conditioning (HVAC) systems that maintain the interior environments of buildings comfortable.

A consortium of Australian universities has produced a range of materials that aim to help young engineers gain insights into how they might make a range of activities more energy efficient. In this exercise you will immerse yourselves in a virtual world in which you are provided with opportunities to design a commercial office building. Many buildings are multi-purpose, and you will be given the opportunity to study how you can design a café/bar and a small industrial process, namely a microbrewery to achieve considerable energy savings. For example, it may be possible to reduce the energy consumption in the café/bar by up to as much as 60% compared with commonly encountered systems by measures such as installing:

- Low energy lighting systems
- A hot water system that is based on a heat pump
- High efficiency taps to reduce the consumption of hot water
- Variable speed fans to remove vapours and odours released by cooking

You will find that you have several other design options to try.

Lighting consumes about 9% of all electricity that is generated and you will able to explore how this can be greatly reduced by choosing low energy lights such as light emitting diodes (LEDs). These consume about one-eighth the energy of incandescent light globes and they last about 20 times longer before they need replacing. Their initial cost is more, but you will be induced to explore the relative costs of the two systems.

You will obtain the results of your design decisions expressed in terms of the:

- Annual emissions of CO_2
- Amount of energy consumed annually by the building
- Annual cost of energy

When you have developed your design, you will present the factors you considered and the results of your findings in an oral presentation to your lecturer and peers. A second output will be a report that outlines your rationale, and you will choose a specialised topic of building-energy design such as thermal insulation, the effects of shading or glazing on which you describe in rigorous engineering detail.

2.0 Benefits you will gain

By becoming familiar with the effects of your decisions on building-energy consumption you will know more or less instinctively the effects of your design decisions – you will have taken the first steps along the road to becoming an expert. In other words, you will have gained what is known as tacit knowledge of energy consumption in buildings. As a result, you will have become well informed about some of the measures we can take to reduce energy consumption in buildings, and you will be able to discuss these with a wide range of people. These include:

- Members of the public who are interested in energy conservation but who have not enjoyed the benefits of a science-based education.
- Fellow professionals in the building and construction industries, such as architects, accountants, building regulators and so on.

The virtual world provides you with an introduction to environmentally sustainable design as it applies to buildings. As your studies develop you will become familiar with the principles of engineering science that underpin the thermal performance of buildings, and you will be able to make creative use of data supplied by building materials manufacturers.

3.0 Your task

3.1 The design brief

You have been allocated a building site that is located in a city that shares a climate identical with that of Melbourne, Australia. The building's footprint is 784 m^2 and it is square. The building is located on a plot of land such that it is not overshadowed by nearby buildings. The vacant building site is shown in Figure 1.

Figure 1. The location of the building site showing neighbouring buildings

The building has a total of five storeys. The ground floor comprises a café and bar as well as microbrewery. The four upper storeys are used as office space. Use the drop down menus shown in Figure 2 are used to develop a building that conforms with the specifications listed above.

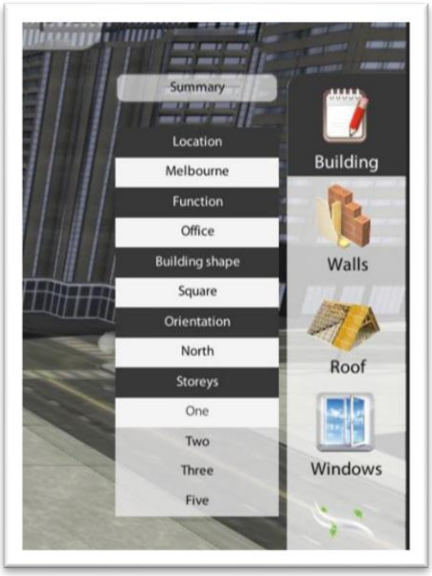

Figure 2. The drop down menu used to specify the basic features of your building

When this task is complete your building will appear as shown in Figure 3. You will see that the building has no roof and the façade needs to be detailed.

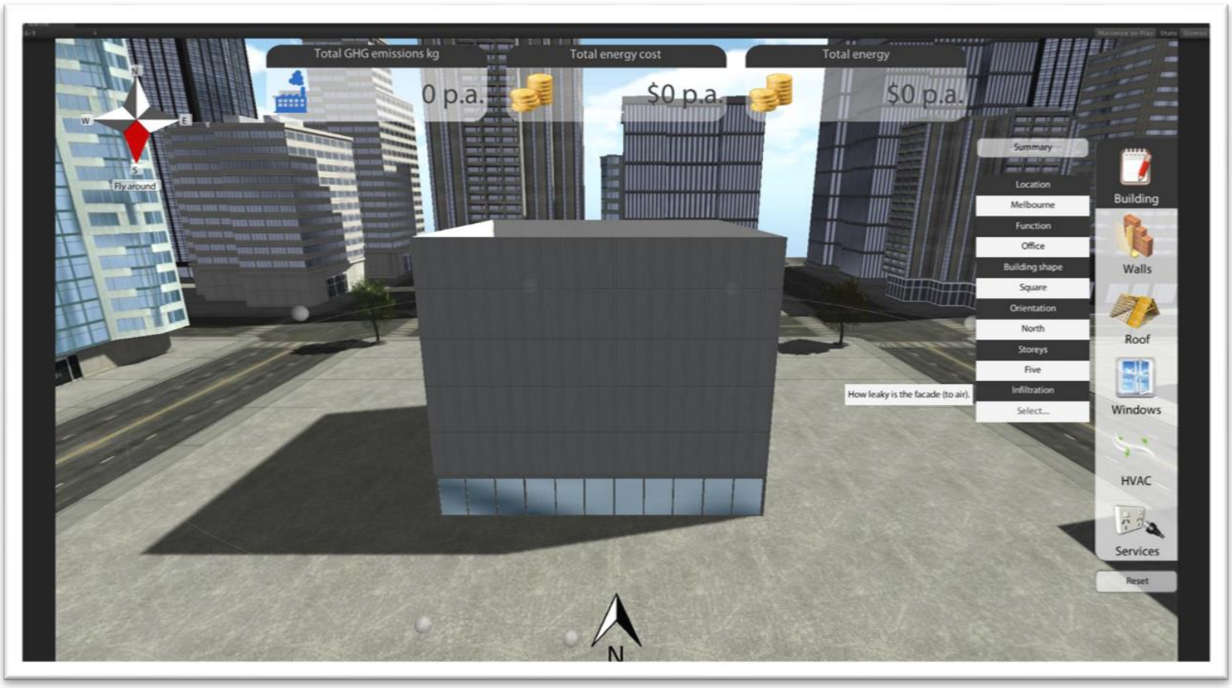

Figure 3. The external shell of your building

You are now able to design the building *ad libitum* using the menus that enable you to detail the walls, the roof, the windows, the heating, ventilation and cooling (HVAC) system and the building services. In several cases you will be provided with choices that represent three different qualities or standards of building construction practice. The lowest standard represents that found in the existing building stock, a higher standard is represented by that mandated for new buildings under the Building Code of Australia, and the third level of energy efficient design is attainable and it typifies 'world best practice'.

3.2 Outcomes

On completing this task, you will have gained:
- An appreciation of the factors that affect energy consumption in buildings.
- A feel for the interdependent nature of design decisions. This applies not only in an engineering sense, but also aesthetically, through regulations, economically and environmentally.
- Tacit or ingrained knowledge of factors that affect consumption of energy in buildings, and this will help you to quickly assess a wide range of design options.

3.3 Outputs

Tangible outputs from your project will be:
- A seven minute presentation on the findings of your work. Your talk should describe why your topic is important. The strategy you used to explore how to specify a low-energy consuming building and your key findings. Describe the special skills that engineers can bring to environmental issues of this kind.
- A written report not exceeding 1000 words. It will cover the material outlined in your talk, but it may contain some finer detail of how you carried out the task.

Virtual Experience Task 2:
An exercise to highlight the creative power of engineering science

Note: The following exercise is designed for more advanced students who are familiar with the principles of heat transfer. It complements the principles of engineering used in the Virtual Experience software.

1.0 Overview

Energy consumption by buildings in Australia is responsible for over a quarter of the nation's greenhouse gas emissions. This is reflected in running costs incurred by the owners and occupiers of buildings.

The energy consumed by existing buildings can be reduced, sometimes by taking simple measures such as installing more efficient lighting systems, or by choosing slightly different settings of thermostats. As we might expect, more opportunities to improve the energy efficiency of buildings present themselves at the design stage. For example, it may be possible to improve the thermal effectiveness of buildings by specifying an appropriate type of glazing materials that is applied to the exterior of a building envelope. Designers can also specify efficient heating, ventilation and air conditioning (HVAC) systems that maintain the interior environments of buildings comfortable.

A consortium of Australian universities has produced a range of materials that aim to help young engineers gain insights into how they might make a range of activities more energy efficient. In this exercise you will immerse yourselves in a virtual world in which you are provided with opportunities to design a commercial building. You will obtain the results of your design decisions expressed in terms of the:

- Annual emissions of CO_2
- Amount of energy consumed annually by the building
- Annual cost of energy

When you have developed your design, you will present the factors you considered and the results of your findings in an oral presentation to your lecturer and peers. A second output will be a report that outlines your rationale, and you will choose a specialised topic of building-energy design such as thermal insulation, the effects of shading or glazing on which you describe in rigorous engineering detail.

2.0 Benefits you will gain

By becoming familiar with the effects of your decisions on building-energy consumption you will know more or less instinctively the effects of your design decisions – you will have taken the first steps along the road to becoming an expert. In other words, you will have gained what is known as tacit knowledge of energy consumption in buildings. As a result, you will have become well informed about some of the measures we can take to reduce energy consumption in buildings, and you will be able to discuss these with a wide range of people. These include:

- Members of the public who are interested in energy conservation but who have not enjoyed the benefits of a science-based education.
- Fellow professionals in the building and construction industries, such as architects, accountants, building regulators and so on.

The virtual world provides you with an introduction to environmentally sustainable design as it applies to buildings. As your studies develop you will become familiar with the principles of engineering science that underpin the thermal performance of buildings, and you will be able to make creative use of data supplied by building materials manufacturers.

3.0 Your Task

Write an in-depth report on one of the following topics:

1. The mechanisms of heat transfer through building elements such as walls. Consider how a thorough knowledge of conduction, convection and thermal radiation can help engineers to develop creative solutions to minimising energy consumption in commercial buildings. Consider how orientation affects the solar radiation falling on the external envelope of the building, and how this affects the temperatures of the external surfaces, hence ultimately the energy consumption. Enhance your report by speculating on how newly emerging materials might be used in the design of energy efficient buildings.

2. The mechanisms of heat transfer through glazed elements of the external fabric of buildings. Consider the orientation of the glazed surfaces and use the principles of engineering science to devise designs of windows that result in a building being energy efficient. Survey manufacturers' data sheets to suggest improved designs of windows. What new technologies are emerging that will assist engineers to specify glazing material that lead to more energy efficient buildings?