Energy reduction in tertiary education buildings: establishing functional area energy consumption benchmarks using the LLO tool

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Abstract

This research establishes comprehensive and improved energy consumption benchmarks for Australian tertiary education facilities. It examines the audit of energy end use in various functional areas in a sample of tertiary education institutions to identify, control and reduce electrical energy used in typical existing campus buildings.

Many Australian universities have data available for energy consumption of their total campus and selected individual whole buildings. However, as the typical tertiary campus is characterised by a large and diversified portfolio of buildings with differing architecture, facades, occupancy and services, energy comparison between buildings does not provide useful information. This differs from energy use and management in general commercial office buildings. Universities also have different disciplines performing different activities that are not directly comparable. For instance, a campus with a medical school or molecular science building (service equipment intensive type) has a different energy use profile from one that does not.

This research develops a common tertiary education functional typology within different campus buildings, grouped according to significant architectural features, energy intensity and use, to establish appropriate energy benchmarks for common functional areas such as offices, lecture rooms and laboratories.

Assessment of these common functional areas by energy audit allows quantitative comparison between functional areas, and between diverse whole buildings. It also provides a rational basis for establishing performance targets for buildings at the early design stage by aggregation of functional areas. Benchmarking these areas allows energy managers to manage by exception and the benchmarking process enables managers to practise continuous improvement.

The knowledge and data from this study enables researchers to focus on those factors that specifically affect energy use for particular activities. This enables building energy managers to discern and rank those major factors that determine energy consumption, allowing them to concentrate their performance efforts on the most energy efficient measures.

The benchmarks derived in this study came from audits of 24 buildings at the University of Sydney campus across a five-year period (2009–2014) comprising over 80 distinct functional areas. Using this data, together with local and overseas sources, the LLO functional area energy benchmark tool was developed. LLO is an acronym derived from the surnames of the researcher and two colleagues who discussed the development of the University of Sydney graduate energy audit program in 2009.

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Abbreviations

AIRAH	Australian Institute of Refrigeration Air Conditioning and Heating
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
bEQ	building energy quotient (United States)
BREEAM	building research establishment environmental assessment methodology (United Kingdom)
CIBSE	Chartered Institute of Building Services Engineers (United Kingdom)
DESC9111	Energy Management in Buildings, graduate subject at University of Sydney
ELF	equipment load factor (DESC9111 LLO spreadsheet)
FEF	fabric efficiency factor (LLO spreadsheet)
GFA	gross floor area
GJ	gigajoule
G08	Group of Eight Australia (Universities)
GP	general purpose building (G08 definition)
HEEPI	higher education environmental performance initiative (United Kingdom)
HVAC	heating ventilating air conditioning
kWh	kilowatt hour
kWh/m^2 pa	kilowatt hour per square metre per annum
LEED	Leadership in Energy and Environmental Design (US Green Building Council)
LLO	Campus Function Area Energy Benchmark Prediction Tool
MJ	megajoule
m^2	square metre
NABERS	National Australian Built Environment Rating Scheme
OLF	operational load factor (LLO spreadsheet)
pa	per annum
PJ	petajoule
SEI	service and equipment intensive building (G08 definition)
TEFMA	Tertiary Education Facilities Managers Association

1 Introduction

1.1 Introduction to the problem

The background of this research is the international imperative for control of human-induced climate change for which greenhouse gas emissions from electricity generation are a significant component. Australia's *National Strategy on Energy Efficiency* (Council of Australian Governments 2010, p. 39) notes that "globally the building sector is accountable for 40% of the world's energy consumption and one third of greenhouse gas emissions". In Australia it is estimated the building sector accounts for approximately 19% of total energy consumption and 23% of greenhouse gas emissions. The *National Strategy* (Council of Australian Governments 2010, p. 40) notes:

> It has been estimated that electricity was responsible for 65% of energy use and 83% of emissions from the commercial sector… space cooling, ventilation and lighting were found to be the most significant causes of greenhouse gas emissions at approximately 71% of total emissions.

The *Draft ACT Sustainable Energy Policy 2010-2020* by Engineers Australia (2010, p. 3) notes that:

> The Mckinsey research... as well as research in support of the national framework for energy efficiency demonstrates... that at least 25% improvement in energy efficiency is possible in the commercial sector.

Energy use is a significant issue for commercial building managers for several reasons, in particular the cost and sustainability. For large institutions with multi-building campuses such as tertiary education institutions and health institutions, energy use is a major cost. Data from the Group of Eight Members of Australian Universities (G08) indicates electrical energy use is, on average, approximately 30% for general purpose(GP) and 50% for service intensive equipment (SEI) of total building operating costs (Kuzcek 2014, p. 4). But there is a lack of useful data to help building managers manage energy use across diverse existing buildings. For comparison, the Property Council of Australia annual survey, *Office Benchmarks Report 2015*, indicates electricity as 6% of total building expenses.

The most authoritative information on the energy use in tertiary education buildings in Australia is published by TEFMA, individual university administrations and the Group of Eight (G08) universities. However, the buildings are categorised in a scheme such that most of this energy data is aggregated into campus or 'whole of dissimilar' buildings, in forms not allowing meaningful analysis. The information is used for benchmarking of annual university operating costs, financial planning, the planning of new buildings, and to the extent currently possible, energy management.

Universities have many different functional areas such as offices, lecture theatres and laboratories. These functional areas have different energy use and management issues. However, there is no readily available data using common functional areas within the widely differing campus buildings, for Australian university buildings, which is essential information for tertiary education building energy analysis.

There is limited energy consumption data available for functional areas for tertiary buildings from overseas sources and it does not correlate well to Australian campus conditions due to climatic, energy source and area classification differences.

The energy use data that is available for tertiary education buildings compares poorly with the quality of energy data currently available in commercial buildings.

1.2 Energy consumption in commercial buildings

The traditional method of management and control of energy consumption in the commercial (non residential) built environment is to collect historical utility-metered data across a wide portfolio of similar buildings, establish typical whole of building benchmarks to use to compare and contrast 'best', 'typical' and 'worst' cases. Managers then proceed with continuous improvement to the worst cases identified to reduce waste and improve energy efficiency using combinations of management, technology and equipment adjustment or replacement.

This comparison method works well when applied to the generally available whole of building data for several reasons including data availability, similarities among commercial buildings and incentives for energy efficiency. A majority of the existing stock of commercial buildings typically have accurate metered utility data available for whole of buildings and tenancies. This means that there is an accurate and rolling data set from a large and statistically significant sample set. In the Property Council of Australia's annual survey *Office Benchmarks 2015*, the summary of expense items for NSW city centre indicates electricity is approximately 6% of total building operating expenses. It should be noted the comparison with the 25% energy costs to operation costs for tertiary buildings from TEFMA is based on differing definition of costs.

Commercial buildings are similar in that they obtain their electrical power from the national power grid (with the addition of limited local power generation from renewable sources in selected current buildings); are generally fully electrically lit and air conditioned; have largely comparable hours of operation consistently over the working year; have occupant behaviours that are broadly similar; and have facades and structure constructed in a broadly similar range for the 1950–2000 era of office buildings. The commercial life of the building, subject to renovations and fit outs, is generally related to similar and ongoing common uses. They have energy consuming services for the base building and tenancies with a similar range of energy intensities (Chartered Institute of Building Services Engineers 2012, Department of Climate Change and Energy Efficiency 2012).

In addition, commercial buildings are occupied by owners and or tenants, depending on terms of the lease, with increasing financial and regulatory incentives for energy efficiency such as Building Energy Efficiency Certificates, National Australian Built Environmental Rating Scheme (NABERS 2015), and Green Star (Green Building Council of Australia 2010) sustainability ratings. These incentives reward the owners and or tenants for documenting their energy use and improving energy efficiency.

1.3 Energy consumption in tertiary education buildings

Tertiary education buildings are a subset of commercial buildings, as opposed to residential apartment or industrial process buildings. University residential colleges are not covered by this study. Tertiary education buildings are different from commercial buildings for several reasons, discussed below focusing on the University of Sydney, which means the building to building energy consumption comparison method is less applicable.

- Tertiary education buildings feature great diversity, characterised by a wide range of facades, structures and architectural styles across a university campus (see for instance, Figures 1, 2, 3 and 4), often constructed over many decades, with differing internal building condition responses to dynamic climatic effects. Renovations and fit outs of education buildings often result in differing use and operations.
- Tertiary education space and energy use varies. Within the buildings, there are diverse faculty and functionally significant areas, with widely differing types of use, energy intensity of installed services and equipment, and behaviour of occupants. Hours of operation and occupation intensity vary greatly throughout semester, non-semester and staff vacation times across the differing functional areas, room types and categories.
- Data availability is relatively (compared to commercial buildings) limited. While accurate utility metering is usually available for the whole campus, and increasingly for individual buildings, it is not generally available at the room level or for functional areas. There has not historically been direct utility cost charging for energy supplied to individual buildings, faculties or, more pertinently, functional areas by room and area types (Collins 2011, p. 22). Utility cost recovery is a relatively recent (within the last five years) feature of campus administrations.

The relationship between the tertiary education sector and general commercial buildings in Australia is shown in Table 1 below.

Table 1 Universities as a proportion of commercial stock and energy use

Non residential, non industrial total building stocks (nett lettable area) (000 m²)

	Nett lettable area	Universities	Universities %
2009	135,726	8,837	6%
2020 (est)	165,970	12,047	7%

Total energy consumption (petajoules)

	All	Universities	Universities %
2009	134.6	7.7	5%
2020 (est)	169.6	11.6	6%

Source: *Baseline Energy* (Department of Climate Change and Energy Efficiency 2012), Table 1.1, 1.2.

1.4 Energy use at the University of Sydney

The University of Sydney, located in inner Sydney across the suburbs of Camperdown and Darlington, is a long-established campus, with the oldest sandstone buildings built in 1859. It has over 50,000 students with 7,000 staff. It is used as a case study for several reasons. It has a diversity of buildings and an *Energy Savings Action Plan* was completed in 2008 (University of Sydney 2008) which included the energy audit of 14 buildings. Further energy audits were conducted of 24 University of Sydney buildings from 2009 to 2014, with full co-operation of Campus Infrastructure Services (CIS) staff, and with participation from trained graduate student audit teams (Obrart 2014), as part of the graduate subject DESC9111 Energy Management in Buildings. This campus was selected as a basis for the study, being typical of a diversified building group and because of availability of resources and information.

Four buildings at the University of Sydney are shown in Figures 1, 2, 3 and 4 and discussed below as indicative of energy use issues. Data is reported in Table 4.

Figure 1 Law Building at University of Sydney, gross floor area 30,069 m², with energy use of 91.1 kilowatt hours per square metre per annum (Table 4)

The building in Figure 1 is used for teaching, lectures, meetings, and offices for faculty and administrative staff, with long hours of use. Compared with average energy use in the *Energy Savings Action Plan* (University of Sydney 2008) of 163.9 kWh/m² pa, it appears to be very efficient but audit survey shows the building is only partially air conditioned. No conclusion can be drawn by comparing this building's energy consumption against another building.

Figure 2 Services Building at the University of Sydney, gross floor area 6,529 m², with energy use of 190.8 kilowatt hours per square metre per annum (Table 4)

The building in Figure 2 is used principally for administration offices and meeting rooms, with standard hours of use. Energy use is similar to the average in the *Energy Savings Action Plan* but the audit shows that, compared to many campus buildings which have lecture rooms and laboratories, it has low energy intensity, so consumption should be significantly less than average.

Figure 3 Brennan MacCallum Building at the University of Sydney, gross floor area 7,500 m², with energy use of 53.0 kilowatt hours per square metre per annum (Table 4)

The Brennan MacCallum building in Figure 3 is used principally for faculty and administration staff with (basement) computer labs, with standard hours of use. Utility data indicates it is a very low consumption, energy efficient building. But audit data shows this building is mixed mode, partially air conditioned with low occupancy and use, so it may not be an energy efficient building due to its low energy intensity.

Figure 4 Holme Building at the University of Sydney, gross floor area 6,760 m², with energy use of 101.9 kilowatt hours per square metre per annum (Table 4)

The Holme Building in Figure 4 is used principally for student catering and amenities. This building with its Victorian architecture facade, high mass masonry building, administration, restaurants, cafe and function rooms, and with long hours of occupancy, appears efficient compared to the average high intensity occupancy and long operational hours of use with major cooking appliances. But comparison between these 24 energy audited buildings, as shown in Table 2, does not lead to any useful conclusion.

1.5 Summary of the problem – the gap in the knowledge

Research from the University of Sydney from energy audits of 24 campus building and from the *Energy Savings Action Plan* (University of Sydney 2008) for 14 campus buildings, as summarised in Table 2 and Table 4 , shows that there is a lack of detailed information to allow comparison of energy consumption between buildings. These findings are supported by both Australian and international research. For instance, the comprehensive Australian publication *Baseline Energy 2012* (Department of Climate Change and Energy Efficiency 2012, p. 86) notes that "precinct level data fails to distinguish between functionally diverse building types, from lecture theatres to physics laboratories, although the level of energy intensity of these buildings is likely to vary greatly" and that "an investigation of the cause of apparent instability of university buildings through time has revealed the primary cause is that the mix of different building sub types within the data sample changes from year to year" (p. 90).

In the United Kingdom, the Chartered Institute of Building Services Engineers review of energy benchmarking for display energy certificates (CIBSE 2011, p. 31) found the guidance in TM46 (CIBSE 2008) should be improved on the use of benchmarking for campus sites where sub metering is not available. This CIBSE 2011 review covers benchmarks for display energy certificates including 2,637 campus buildings. Display Energy Certificates are a prescribed document, defined by UK Government regulation " The Energy Performance Of A Building Directive" which must be displayed in public buildings and which indicate the actual measured energy use, mandatory from 2008. The information from these certificates is registered in a landmark national register which was used for the CIBSE review.

The conclusion is that historical energy consumption data, per campus or per building, does not provide information useful to identify, predict, manage and reduce energy consumption in mixed use campus buildings, due to the widely differing energy intensities, uses, hours of operation and building architecture within the functional or academic areas within buildings. Improvement in energy consumption, from a whole of building to whole of building annual comparison, does not provide useful data. This leads to a gap in knowledge in managing energy use in tertiary education buildings.

For Australian tertiary building functional area energy consumption data, *Baseline Energy* (Department of Climate Change and Energy Efficiency 2012, p. 95) notes that “A key conclusion to this study is it is necessary to resolve functionally distinct building types and end issues to understand the energy consumption of tertiary education buildings in Australia”. The lack of energy consumption data available which informs the comparison between common functional areas within dissimilar buildings, allowing identification of good to poor practice and application of energy efficiency measures, is a significant problem. It means a university building or facilities manager tasked with identifying and reducing energy consumption across the campus within the building (or part, as faculties and departments can and do share buildings) has no clear path to success if they only have access to whole of campus or whole of building data.

The reason is that the energy consuming services are tasked to serve specific functions, not simply a generic ‘office’ space, so controls, degree of service, hours of operation, are purpose designed, such as administration offices (irregular hours), computer labs (high density) and many related examples.

This means any energy efficiency measures which target the whole of building (or campus) are most likely not to be optimum due to not being able to provide a required level of service required by a particular functional area. For instance, lighting and air conditioning ‘off’ after normal office hours is unsatisfactory for academic and laboratory and lecture room use. This issue of application of energy measures is discussed in more detail in Chapter 5.

Functional area data to establish benchmarks or provide actual data can be determined from energy auditing, sub metering or predictive modelling, discussed in Chapter 4.

A solution would be to use functional area benchmarking to identify areas with high, typical or low energy consumption. This would then prioritise the application of the industry established energy efficiency measures being applied to lighting, heating, ventilation, air conditioning, and other equipment, leading to energy savings by appropriate changes in operational behaviour.

Illustration of the gap in knowledge

The audit summary in Table 2 and Table 3 illustrates the gap in knowledge as these individual whole of building energy consumption varies between 111.9 and 407.7 kilowatt hours per square metre per year (403 to 1,468 megajoules per square metre per year).

Similarly the 24 buildings audited in the subject DESC9111 (Obrart 2014) with a total gross floor area of 156,980 m² as part of this research project from 2009 to 2014, summarised in Table 4, show building consumption which varies between 54 and 237 kilowatt hours per square metre per year.

These differences in average whole of building energy intensities do not provide useful information for energy reduction activities, without the addition of functional area benchmark analysis to highlight where the variations in energy intensity are occurring (see Table 6).

Note that the *Energy Savings Action Plan* (University of Sydney 2008) indicates gas energy represents less than 18.5% of the total energy consumed. Gas sub metering per individual building is not generally available.

Table 2 Results from energy audit for *Energy Savings Action Plan* 2008 at University of Sydney: summary by building

Building		Gross Floor Area (m²)	Energy Cons (GJ)	Energy per GFA (GJ/m²)
A12	Macleay Bldg	3,914	5,463	1396
A16	Badham Bldg	4,608	3,632	788
A20	Woolley Bldg	7,640	3,791	496
A35	Education Bldg	9,501	5,411	570
F03	Fisher Library	23,078	13,578	588
F07	Carslaw Bldg	17,225	6,942	403
F11	Chemistry Bldg	12,567	13,473	1072
F13	Anderson Stuart	9,709	7,554	778
G04	Wilkinson Bldg	11,313	6,160	545
G06	International House	8,567	3,903	456
G08	Biochemistry Bldg	11,840	17,384	1468
G12	Services Bldg	6,825	5,178	759
H04	Merewether Bldg	7,428	3,237	436
J01	Chemical Engineering	4,467	4,583	1026
Totals		**138,682**	**100,289**	**723**

The totals indicate the extent to which the Darlington and Camperdown campuses have been audited.

- By floor area 138,682 of 343,404m² or **40%** of the campus has been recently audited
- By energy approx. 100,289 of 269,503GJ or **37%** of the campus has been recently audited

Below is the same data in graphical form, broken down into gas and electricity components.

Source: *Energy Savings Action Plan* (University of Sydney 2008, p. 30).
Notes: Average energy consumption is 200.8 kWh/m² pa (723 megajoules/m² pa) over 14 audited buildings with gross floor area of 138,600 m² representing 40% of the campus. These aggregated results, while useful, do not assist in comparing the energy efficiency of the 14 buildings.

Table 3 Results from energy audit for *Energy Savings Action Plan* 2008 at University of Sydney: proportions of energy use by consumption type

Application	Energy Source	Annual Consumption (kWh/y)	(GJ/y)	Annual Cost ($/y)	Perform. Index (MJ/m²/y)	Proportion of Total Energy Consumption (%)
Lighting	Electricity	4,304,344	15,496	$357,901	112	15%
Cooling and Ventilation	Electricity	7,491,358	26,969	$622,898	194	27%
Heating	Electricity	2,092,882	7,534	$174,021	54	8%
	Gas		14,062	$102,235	101	14%
Amenities	Electricity	785,294	2,827	$65,296	20	3%
	Gas		16	$116	0	0%
Elevators	Electricity	310,857	1,119	$25,847	8	1%
Office Equipment	Electricity	3,723,905	13,406	$309,638	97	13%
Other Equipment	Electricity	3,806,120	13,702	$316,474	99	14%
	Gas		1,479	$10,754	11	1%
Hot Water	Electricity	197,953	713	$16,460	5	1%
	Gas		2,966	$25,782	21	3%
Totals		22,712,712	100,289	$2,027,422	723	100%

Source: *Energy Savings Action Plan* (University of Sydney 2008, p. 31).
Notes: Electricity use is 22,712 kWh pa divided by 138,600 m² gross floor area = 163.8 kWh/m² pa for electricity only. Lighting, cooling, ventilation and heating accounts for 64% of the total energy use.

Table 4 Comparison of actual electrical energy consumption and predicted consumption for 24 buildings at the University of Sydney

ID No.	Gross floor area GFA in sqm	kWh p.a. per m² (based on CIS data)	**Actual (CIS) Usage data kWhr/yr	Year (actual) Data**	Audit year	Audit Estimate kWhr/yr	Difference per cent audit to CIS Actual	Typical electrical consumption kW (Approx) Base load	maximum
A28 PHYSICS	8404	98.6	829,400	2008	2009	798,200	-4	80	180-200
F12 TRANSIENT	2261	84.0	185,000	2008	2009	209,100	+13	10	50-60
H12 BOOK REPOSITORY	2133	70.3	150,000	2008	2009	146,600	-2	10	30-40
J13 LINK	3844	114.72	441,000	2008	2009	531,700	21	30	-
J02 PNR & OLD SCHOOL	3931 +278	87.6	344,400	2008	2009	351,800	+2	25	-
D02 COPPLESON	1219	94.8	120,000	2009	2009	114,700	-4	15	40-50
F19 EASTERN AVE	3046	145.2	442,400	2008	2009	427,300	-3	40	-
A29 PHYSICS	1738	116.2	202,100	2009	2009	196,200	-3	20	-
G04 WILKINSON	12065	130.6	1,574,000	2009	2010	1,680,000	+7	130	-
J03 ELEC ENGINEERING	9396	76.0	715,000	2009	2010	681,750	-5	50	150-200
A18 BRENNAN MCALLUM	7280	54.9	400,000	2009	2010	454,243	+14	40	-
A09 HOLME	6760	101.9	689,000	2009	2010	631,385	-8	45	150-180
D04 BOSCH	2009	172.7	347,000	2009	2010	331,000	-5	N/A *	-
G09 NOEL MARTIN	6649	225.9	1,502,000	2009	2010	1,524,176	+1	N/A *	-
H69 ECONOMICS	6844	225.8	1,546,000	2009	2011	1,572,983	+2	N/A *	-
A23 MANNING HOUSE	3952	236.0	933,000	2009	2011	937,862	+1	N/A *	-
G01 WENTWORTH	10399	216.8	2,254,410	2012	2011	2,691,146	+19	90	80-320
G12 SERVICES	6529	190.8	1,246,000	2012	2012	1,327,375	+7	70	180
M02 MALLETT ST (A,B,C,D)	12527	203.9	2,553,981	2012	2012	2,274,417	-11	90	200-240
F10/10A LAW	30069	91.1	2,765,884	2012	2013	2,846,533	+3	104	-
A35 EDUCATION	10,138	117.8	1,194,553	2012	2013	1,169,526	-2	60	140-180
A36 ANNEXE	1167	116.9	136,468	2012	2013	117,353	-14	N/A *	-
F07 CARSLAW	17022	120.8	1,928,333	2014	2014	1,972,875	+3	39	120-140
B22 VET	1939	179.98	349,000	2014	2014	325,897	-6	10	100-120

Sources: Actual energy consumption from Campus Infrastructure Services data; audit energy consumption from DESC9111 audit team (2009 to 2014) (Obrart 2014). N/A* - not available at time of audit

The Group of Eight Australia (G08) of Australian universities commissioned a GO8 Space Project (Kuzcek 2014). In addition to whole of campus data, it provided data on the energy intensity split between general purpose (GP) and service and equipment intensive (SEI) buildings. Average energy use for general purpose buildings is 172 kWh/m² pa (gross floor area), with a range of approximately 80-205 kWh/m² pa. Average energy use for service and equipment intensive buildings is 555 kWh/m² pa (gross floor area), with a range of approximately 360-950 kWh/m² pa.

This typical data is an improvement on non segregated buildings but is too broad to be useful, as it is insufficient in detail to compare between buildings, for the purpose of identifying good to poor practice identifying inefficiencies to lead to choices and application of energy efficiency measures.

1.6 Research aims and methodology

To address the gap in knowledge on the energy use of tertiary education buildings, the research has six aims.

1. Provide meaningful disaggregation of data to establish more accurate energy consumption benchmarks for tertiary campus buildings by disaggregating 'whole of building' data (see Tables 2, 3 and 4) to individual but generic functional areas.

2. Establish useful functional area benchmarks by use of the LLO tool to compare and contrast across common functional areas such as lecture rooms and computer laboratories in different buildings, to indicate relative energy efficiency.

3. Validate the concept of functional areas in campus buildings for identification and control of energy consumption.

4. Improve selection and application of energy efficiency measures to overcome the problem that typical energy use varies by consumption type (University of Sydney 2008, p. 31; Department of Climate Change and Energy Efficiency 2012, p. 7). For example, typically cooling, heating and lighting account for over 60% of whole of building energy consumption. This may not be an effective source of information (depending on the building systems, services and controls), to develop energy efficiency measures for mixed use, multi functional area campus buildings.

5. Identify standing or base load consumption to quantify high after hours energy base (or standing) load (see Table 4) with subsequent appropriate action, as it is an important source of energy saving such as equipment running when not required for safety or function.

6. Rectify poor aggregation of data, to overcome the problem that neither of the comparisons between differing energy consumption of the *Energy Savings Action Plan* (University of Sydney 2008) (14 buildings) or Obrart (2014) (24 buildings) or the annual surveys from TEFMA including 40 Australian campuses, provides information about the energy efficiency of any particular building due to the aggregation of data to a meaningless total and average in widely differing buildings and uses.

The research methodology used to address the research aims by developing and validating the LLO tool is detailed in Chapter 4.

1.7 Structure of the thesis

The thesis is structured as follows.

Chapter 2 reviews the extensive literature on energy in commercial buildings and normalised energy consumption in the built environment, to identify and critically survey the key sources of current knowledge.

Chapter 3 reviews the literature and data on energy use in tertiary education in the UK, USA and Australia.

Chapter 4, research methodology defines key terms, particularly benchmarking and presents the methodology to collect data including the choice of room by room building audits, together with details of the training of the audit teams, survey process, data recording and corrections, and involvement of the building occupants, generating operational data to establish functional area consumption benchmarks. Difficulties with data collection, accuracy of inputs and outputs are discussed. Alternative audit methods for data collection are reviewed including correction of raw audit data and LLO benchmarks and accuracy of results with sensitivity analysis, benchmarks and LLO prediction tools, Design Builder modelling, feedback from potential users of this information and the LLO tools, 'reality check' and conclusion.

Chapter 5 discusses selection of energy efficiency measures as informed by functional area data, lighting, HVAC applications to existing buildings, standing and base load energy consumption, with extensive examples, barriers to use of functional areas, technical and not technical, applications to new buildings and conclusions.

Chapter 6 summarises the contribution to addressing the knowledge gap and further research directions.

The appendices include a range of data referred to in the thesis.

2 Literature review: energy use and benchmarking

2.1 Introduction

The purpose of this literature review (Hart 1998) is to provide a coherent narrative, identify and critically survey the key sources in the current knowledge, review the theories and debates, then identify questions needing resolution, leading to identifying the gap in the knowledge, and positioning this research in the current literature.

The literature review is reported in two chapters. This chapter reviews the context for energy use in Australia, energy use for commercial buildings, and energy rating and benchmarking tools. Australian and international tools are reviewed to identify gaps in the knowledge. The following chapter reviews energy use for tertiary education buildings overseas, in Australia and at the University of Sydney.

Kempener (2007, p. 3), in a review of low energy high rise for the Warren Centre at the University of Sydney, noted “the amount and diversity of literature addressing energy efficiency issues in office buildings is overwhelming and difficult to summarise and representative of the complexity of the problem”.

There are many sustainability rating tools which include energy consumption as a component. The focus in this thesis is on the rating systems based on energy consumption only.

The most significant area for review is that of existing building energy benchmarking tools, principally from industry organisations, internationally recognised for their expertise in this area. International guides include CIBSE *Guide F: Energy Efficiency in Buildings* (CIBSE 2012), CarbonBuzz (2015), Building Energy Quotient (ASHRAE 2015), Energy Star (US Environmental Protection Agency 2015), and Standard 100 (ASHRAE 2015) and in the Australian context, Green Star Education V1 (Green Building Council of Australia 2009) with no apparent changes to the benchmarks as referenced in standard practice benchmark summary, version 1 (2009). The energy audit process as the method of collecting data is reviewed.

2.2 Energy policy in Australia

Commercial buildings, including tertiary education buildings, operate within an energy policy and regulatory environment in Australia.

Energy efficiency policy In Australia

The public discussion paper *National Building Energy Standard Setting, Assessment and Rating Framework* (March 2010) was part of the *National Strategy on Energy Efficiency*, initiated by the Council of Australian Governments (2010) to co-ordinate all government agencies. The discussion paper noted “all jurisdictions will work together to develop consistent outcomes based on national building energy standard setting, assessment and rating framework for driving significant improvement in the energy efficiency of Australian building stock” (Department of Climate Change and Energy Efficiency 2010, p. 1).

This high level document recognises that the requirement for energy efficiency strategies will need to include different buildings and different sustainability elements of buildings. In discussing measurement metrics, it notes (p. 16, sect. 5.4 Normalisation of Building Ratings According to Building Function) separate metrics for residential and commercial buildings are desirable. For example, annual greenhouse gas emissions per floor area (commercial) and per occupant (residential). A disadvantage is that it is harder to compare energy efficiency of buildings across different building classifications. This is a step towards recognising functional areas. Appendix B of the discussion paper provides useful background information on buildings' contribution to energy use and greenhouse gas emissions.

Energy policy framework for buildings in Australia

The Australian Government's *Energy White Paper* (Department of Industry and Science 2015) is a high level review paper which overviews the latest federal government energy policy framework and its application to buildings. In reference to buildings the paper (p. 10) comments "energy productivity of buildings is determined by thermal properties of the building shell, the way the building is managed and appliances used in it".

In broad summary, Australian Government Energy Policy indicates Australia's competitive edge is reliant on the abundance and diversity of energy sources which in turn requires maximum efficiency in the utilisation of our energy consumption together with energy market reform.

2.3 Energy use in commercial buildings

Energy use in commercial buildings in Australia, that is excluding residential and industrial buildings, is comprehensively revised in the referenced document *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia Part 1* (Department of Climate Change and Energy Efficiency 2012).

The study in 2009 covered 134 million m² of commercial building stock. This stock increased by 20% over the decade from 1999 and is projected to grow by a further 23% over the 11 years from 2009 to 2020. University building floor area is projected to grow from 8,800,000 m² in 2009 to 12,000,000 m² (net lettable area) in 2020.

The study reports that total energy consumption in 2009 is estimated to be about 135 petajoules which represents about 3.5% of the gross final energy consumption in Australia in 2009. This figure is expected to rise by 24% over the period 2009 to 2020, due to population growth, increasing economic activity, growing stock of commercial buildings and energy intensity trends that vary considerably by building type.

The energy and fuel data relates to 388 individual tertiary buildings. The national (2009) average energy intensity is around 869 megajoules/m² (241.2 kWh/m²) which compares credibly with the 14 building study average of 723 megajoules/m² from the *Energy Savings Action Plan* from the University of Sydney (2008), discussed in the next chapter.

Low Energy High Rise by Kempener (2007) for the Warren Centre at the University of Sydney provides a very useful starting point for information on energy use in buildings. The report notes (p. 1):

> The aim of this project is to engage commercial building owners, investors, tenants and contractors and suppliers in developing a suite of initiatives to overcome non technical barriers to energy efficiency in commercial buildings (refurbishments – not new building).

Although the principal focus of this report is office buildings, not campus buildings, the foreword of Kempener (2007) notes:

> The amount and diversity of literature addressing energy efficiency issues in office buildings is overwhelming and difficult to summarise and representative of the complexity of the problem.

The bibliography in Kempener (2007) represents a comprehensive summary of the pre 2007 literature regarding energy efficiency in buildings, none of which appears to mention campus buildings or the concept of functional areas with differing energy densities in any buildings. The quantitative information relating to energy consumption in Australian office buildings is more comprehensively dealt with in *Baseline Energy* (Department of Climate Change and Energy Efficiency 2012).

2.4 Energy rating and benchmarking tools

A number of tools and schemes have been developed in both Australia and overseas to report and manage energy use, both in the design phase and operational phase of buildings. These are reviewed to identify gaps in knowledge.

These rating tools are categorised as Australian Tools (section 2.4.1) and International Tools (section 2.4.2/2.4.3). An overview is provided for these rating tools indicating their scope and application.

2.4.1 Australian tools and studies

Non residential building benchmarking in Australia

The *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia* study released in 2012 by the Department of Climate Change and Energy Efficiency (authored by Department of Climate Change and Energy Efficiency in conjunction with Pitt and Sherry for BIS Shrapnel and Exergy Pty Ltd) provides a comprehensive background to energy benchmarking. The letter of introduction notes the report "is intended to become a shared and public resource... It will fill a significant gap in our shared knowledge of this important sector... Will involve compiling a database which will be populated with data on energy consumption" (Department of Climate Change and Energy Efficiency 2011).

On the accuracy and use of data, the *Baseline Energy* report comments that **"**we note that the precinct level data fails to distinguish between functionally diverse building types, from lecture theatres to physics laboratories, although the energy intensity between these building types is likely to vary greatly" (p. 86) and that the "eight tertiary institutions surveyed did not define or interpret these data codes in the same way, or undertake benchmark reporting in the same way" (p. 86).

Further, the *Baseline Energy* report concludes that "a key conclusion of this study is it is necessary to resolve functionally distinct building types and uses to model accurately the energy consumption of tertiary education buildings in Australia" (p. 95). The overall conclusion is that "as with other building types, data on energy end use in tertiary education buildings is poor" (p. 95).

Much of the volatility in the data appears to be linked to the inclusion of functionally distinct sub types with widely differing energy intensity, within one building category. This is most apparent in the results reported for universities where, for example, laboratories, cafes and lecture theatres are compiled together. This further supports the gap in the knowledge addressed in this thesis.
The two pre-eminent rating systems in use for commercial buildings in Australia are Green Star and NABERS (National Australian Built Environment Rating Scheme).

Green Star

Green Building Council of Australia has developed a series of Green Star sustainability rating tools (operating in Australian since 2003) based on the BREEAM (UK) and LEED (US) methodologies (discussed in the following section) which include a wide range of sustainability tools, resulting in a rating for assessed sustainability.

The Green Star rating assesses overall sustainability (see Table 5 below) with no individual output indicating energy efficiency other than in Green Star Education V1 which does include an energy rating tool for tertiary campus buildings via modelling (see Chapter 3 of this thesis) and benchmark comparison.

Table 5 Green Star Education V1 rating scorecard

Category weightings	**NSW**
Management	10%
Indoor environment quality	20%
Energy	25%
Transport	10%
Water	15%
Materials	10%
Land use and ecology	5%
Emissions	5%
Weighting	100%

Source**:** www.gbca.org.au/green-star

Green Star methodology is not designed to rate energy use or provide energy benchmarks for whole of buildings or functional areas in mixed use buildings. It is based on the consideration of the following independent variables:

- building fabric
- lighting power density
- lighting zoning
- supplementary systems
- appliances and equipment
- HVAC systems
- renewable energy.

The tool uses NABERS energy rating for the prescriptive assessment rating. Where an alternative performance path is desired, energy modelling is used, based on the National Construction Code and Building Code of Australia section J Energy Efficiency, JV3 methodology.

Neither of the above rating tools add to the gap in the knowledge to allow comparison of energy consumption between or for functional areas in tertiary education buildings.

NABERS

NABERS (National Australian Built Environment Rating Scheme) is a national environmental performance rating scheme for commercial buildings. The scheme has existed for over ten years, managed nationally by the NSW Office of Environment and Heritage, on behalf of the Commonwealth, state and territory governments.

The rating scheme provides individual (not combined) ratings for energy, water, waste and indoor environment. The criteria for energy rating are:

- area (gross floor area)
- number of computers (as a measure of occupancy)
- hours of operation (at a defined level of occupancy)
- postcode (for location ambient conditions)
- energy consumption (utility bills).

Figure 5 shows the steps in the NABERS rating.

Figure 5 NABERS rating steps

Source: www.nabers.gov.au/

The wide success of the NABERS energy rating scheme is evidenced in several ways:

- The Property Council of Australia includes NABERS energy targets in its *Guide to Office Building Quality* matrix.
- The Australian Government Department of Industry which manages a mandatory program to improve the energy efficiency of large office buildings (over 2,000 m²) requires owners or tenants to obtain a valid building energy efficiency certificate which includes a NABERS energy rating under the *Building Energy Efficiency Disclosures Act 2010*.
- Local government departments require NABERS ratings as a condition of lease.

- The NABERS 2014-2015 annual report indicates 15,311,428 m² of office space was rated, representing 57% of the national office market (NSW Office of Environment and Heritage 2015, p. 24).

The NABERS energy rating can be applied to whole of building, base building or tenancy (as defined in the NABERS protocol).

The Industry Survey Report on the NABERS rating tool, co-ordinated by AIRAH (2012) on behalf of the NABERS stakeholder advisory committee, provides a comprehensive response from over 100 written submissions, with (p. 10) the “majority of these comments were overwhelmingly positive in their response to NABERS”. A constant criticism is difficulties in application to small or non typical buildings.

The NABERS protocol includes the ability to (unofficially, not for external publication) self rate using the reverse energy calculator available on the NABERS website, which is most useful for practitioners carrying out ‘what if’ design assessments.

Overall, the NABERS commercial energy tool is successful due to:

- rigorous training, including ongoing random third party audits of NABERS assessors
- strong conditions on the accuracy of input data such as copy of actual utility bills, space plans, lease terms for occupancy
- straightforward building and operational input criteria
- a mechanism to have ‘rulings’ from the administrator to clarify anomalies is available.

The NABERS energy tool is designed for whole of commercial building (base building or tenancies) rating and not for tertiary campus buildings (due to their great diversity), but for specified other commercial uses, for example hotels and shopping centres.

The tenancy option is not similar to a campus functional area because the NABERS tenancy criteria does not allocate the central building services energy consumption, from cooling and heating, or lift plant, in any proportion to the tenancy, so any energy consumption benchmark from the tenancy NABERS reverse calculator, would not be useful for campus building functional areas due to inaccuracies of input data.

National Standard on Energy Efficiency

The *National Building Energy Standard Setting Assessment and Rating Framework* (2012) by the Department of Climate Change and Energy Efficiency seeks to define new minimum standards for energy efficiency, in commercial and residential buildings to come into effect between 2015 and 2020. To achieve these outcomes, regulation including rating tools will be required. This paper seeks stakeholder feedback on the proposed tool rating framework.

The preface indicates “in 2011, the value of approved building work was nearly $75 billion, with $47 billion of this spent on residential building work. The building sector accounts for around 19% of Australian energy consumption and 23% of its carbon emissions” (p. i).

The paper discusses existing National Construction Codes regulations and NABERS ratings for energy, and the Green Star reference of the NABERS rating for energy. It notes (p. 15) “the framework will not require a single sustainability rating for buildings, rather distinct sustainability elements (e.g. energy, water, EQ) will be assessed, rated and reported separately”.

The building elements covered include:

- building envelope
- fixed appliances and equipment, such as space heating, cooling, ventilation
- hot water heating systems
- lighting
- other mechanical services
- energy control systems
- on site or directly connected energy generation
- portable plus in appliances.

This high level document indicates for energy efficiency, separate reporting for energy consumption rather than combined sustainability ratings and refers to building elements to be covered, all of which are addressed by the LLO tool.

The Australian Institute for Refrigeration, Air Conditioning and Heating (AIRAH) co-ordinated a response (July 2012) to the framework document which in summary records:

- energy benchmarks be made available to establish (p. 6) "where we are now with real data"
- post occupancy performance verification is essential . "Data collection, analysis, collection and publication are important aspects of the framework and will be required for ongoing evaluation and success" (p.18).
- embodied energy needs consideration . "Embodied energy includes stationary energy (building materials), manufacturing energy (construction buildings) - reductions in embodied energy have the potential to provide large opportunities for energy savings" (p.9).
- existing (not just new) buildings must be included "renovating or retrofitting existing buildings for energy efficiency needs to be incentivised" (p11) to ensure the energy consumption in this category of building works is appropriately controlled
- past and current regulatory effects on energy efficiency, particularly National Construction Codes Section J - 2006 and 2010 requirements should be quantified. "The concept of scheduling future stringency increases for NCC (BCA vol. 1 & 2) is strongly supported so that Industry is aware when these will be implemented" (p.11).

AIRAH (2012, p. 6) notes “when delivering system or building energy efficiency or consumption improvements, AIRAH always recommends to benchmark a starting point, set goals, measure and monitor outcomes, against the project goals”.

2.4.2 International sustainability rating tools

LEED and BREEAM

The two pre-eminent (English language) internationally recognised building sustainability or environmental rating schemes are LEED (USA) and BREEAM (UK). These schemes are the forerunners of the Green Building Council of Australia Green Star rating scheme.

These two international schemes and the Australian scheme are aimed at high performance, top end (in terms of capital expenditure) buildings with the intent of transforming the design strategy, to address a wide range of sustainability issues to improve the built environment. The criteria rated typically include:

- management
- health and well being, indoor environment
- energy
- transport
- water use
- materials
- waste
- land use and ecology
- pollution/emissions
- innovation.

The schemes, including Green Star in Australia, have an algorithm to compute a total output score to provide an overall building sustainability (including but not separately identifying energy) rating or classification, good to outstanding – one to multiple stars, based on a tightly defined input to each of the attributes listed.

The documentation is necessarily very detailed. The assessment, for official publication, must be done by accredited professionals and fees paid to the organisation. There are a range of ratings from design to occupation over differing types of buildings, offices, health care and schools.

The current LEED V4 (2015) appears to rate whole of buildings. The energy consumption input for the LEED rating is determined by the Energy Star rating scheme. The BREEAM Education (Issue 4.1 2012) also rates whole of buildings, however documentation does mention *bespoke* criteria and there appears to be limited scope for the aggregation of functional areas into total buildings, from the energy segments of these sustainability ratings.

In commenting on LEED (US) and BREEAM (UK) Hyde et al. (2007, p. 187) state recent research has questioned whether these systems are achieving this objective. Spielvogel (2015) also strongly criticises the LEED methodology and accuracy.

Generally these tools are not designed to provide campus building functional area energy data or benchmarks.

2.4.3 International energy rating tools

Benchmarking commercial buildings in the United Kingdom

Bruhns et al. (2011) reviewed on behalf of the Chartered Institute of Building Services Engineers (CIBSE) the use of display energy certificates, first published in 2008 by CIBSE as *TM46 Building Energy Benchmarks* (CIBSE 2008*).* Display energy certificates were a UK government initiative with legislation to mandate the recording and publishing of energy consumption data in UK commercial buildings. This review covers 45,000 records from certificates from sites through the UK up to February 2010.

The intent of TM46 classification benchmark categories is to provide activity based groupings of building stock, into benchmarks, allowing building energy consumption comparison, building category to building category and year on year; to assess energy performance and assist in reduction of energy use.

This review covered 2,637 university campus buildings. Key issues identified were that TM46 benchmarks for university campuses were largely based on data from whole sites, not individual buildings. For the future, Bruhns et al. (2011, p. 32) recommend:

> With the disaggregation of a site into individual buildings, it is likely the rules (that is TM46 benchmark categories) need to permit greater flexibility in categories allowed as part of mixed use so individual buildings can be better represented... As part of mixed use university building

For technical benchmarks, Bruhns et al. (2011, p. 37) recommend:

> Work is necessary to develop a technical approach to underpinning benchmarks for all buildings and categories in order to understand how energy demands of representative buildings are built up from specific end users.
>
> For most buildings, the most useful benchmark is their performance in the previous year. Comparison with peers is a secondary level of information (p. 11)

This supports the functional area gap in the knowledge addressed in this thesis.

The foreword to the CIBSE *TM54 Evaluation of Operation Energy Performance of Buildings at Design Stage* (CIBSE 2013) seeks to address a problem and notes:

> There has been growing awareness for some time that many 'low energy buildings' use more energy than designers thought they would. As energy costs have risen, this awareness has started to spread to building owners, who hear much about low energy buildings and subscribe to programmes that rate the design of the building, only to find that their 'low energy design' turns out to have a typical energy bill. The performance of low energy designs is often little better, and sometimes worse, than that of an older building they have replaced, or supplemented.
>
> This phenomenon is not restricted to the UK, but has been observed as far afield as the US and Australia. There is a mismatch between the expectations around the performance of new buildings and the reality of the utility bills. This difference between expected and realised energy performance has come to be known as the 'performance gap'.
>
> There are two main reasons for this performance gap. The first is that the method of calculating energy use for the purposes of compliance does not take into account all the energy uses in a building. In particular, it does not address energy used by lifts and escalators, for catering facilities or for server rooms. This energy use can be substantial: in one case study, The National Trust HQ at Swindon, it was found that 60% of the energy use, that for server room and the

catering, was used in just 3% of the floor area, and more than doubled the operational energy use over the design estimates.

The second reason for the performance gap is related to site practice. To deliver a building that uses as much energy as expected requires that the design is built as intended, the engineering systems are commissioned effectively and the operators and occupiers of the building understand how to operate and maintain the building so that it delivers the expected performance.

Justin Snoxall, head of business group British Land, notes in the preface to this document (CIBSE 2013) that “research has shown that new buildings, once operated, typically consume between 50% and 150% more energy than original expectations”.

This document detailed a comprehensive critique of the current status of dynamic simulation modelling and provides guidance as to how the common deficiencies, not taking into account of operational issues sufficiently, leads to the ‘performance gap’.

The CIBSE TM54 Chapter 7 Methodology thoroughly sets out, step by step, analysis of factors contributing to energy consumption in a typical building, with worked examples, sensitivity analysis and comparison to CIBSE *Guide F* (2012) benchmarks in Chapter 20. CIBSE presents benchmark data in the form of high, likely, midrange range, low end, worst case as indicated in the figures below.

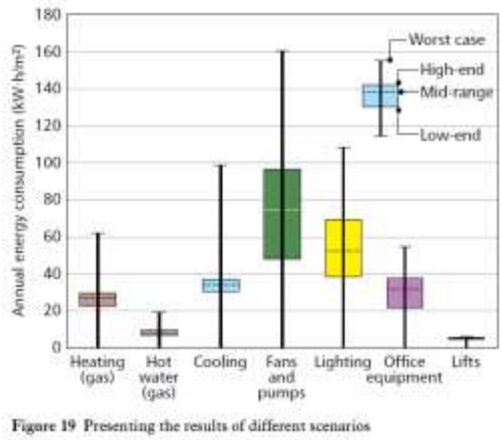
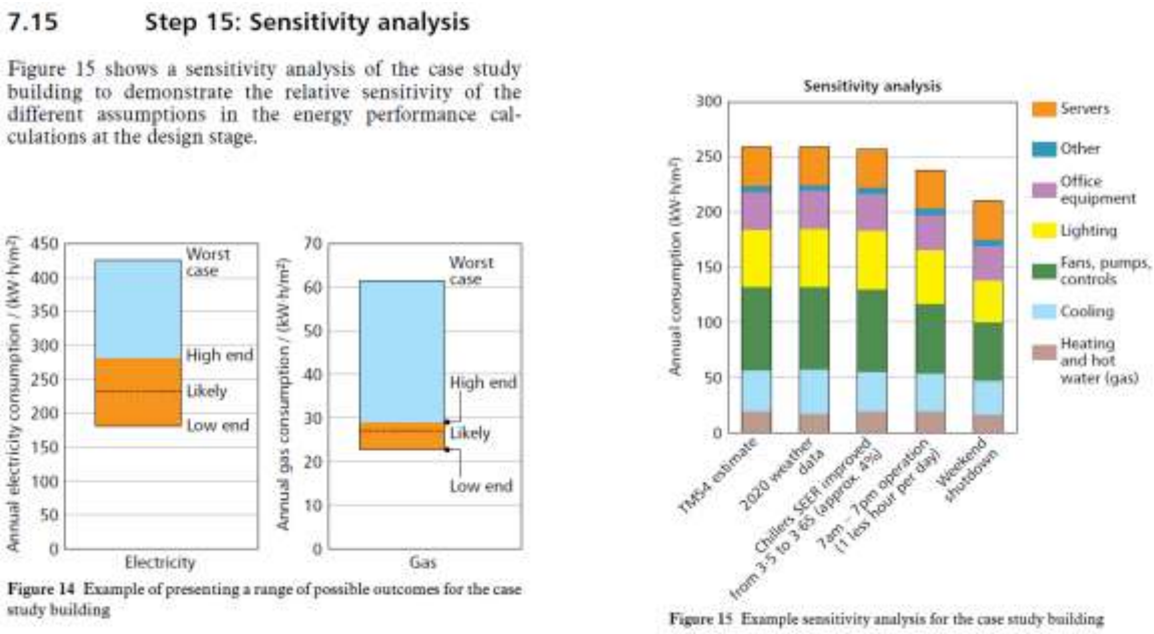


Figure 6 Evaluating operational energy performance
Source: CIBSE TM54 (2013) Evaluating operational energy performance, section 7.15, Figure 19.

This chart indicates a summary of annual operational energy consumption predicted by calculation (method as per CIBSE TM22), broken down into equipment end use type, with sensitivity analysis indicating the range of predicted results, high to low energy use.



7.15 Step 15: Sensitivity analysis

Figure 15 shows a sensitivity analysis of the case study building to demonstrate the relative sensitivity of the different assumptions in the energy performance calculations at the design stage.

Figure 14 Example of presenting a range of possible outcomes for the case study building

Figure 15 Example sensitivity analysis for the case study building

Figure 7 Evaluating operational energy performance – sensitivity analysis
Source: CIBSE TM54 (2013) Evaluating operational energy performance, section 7.15, Figures 14 and 15.

These charts indicate a sensitivity analysis for annual calculated energy consumption for a sample case study building, indicating (CIBSE TM22 method) a range of results over energy source and equipment uses. The variation shows the importance of reviewing assumptions with prospective operations - indicating assumptions with the results - the opportunity to reduce energy use in operation (as well as design) and where to focus attention.

CIBSE TM54 (2013, p. 16) includes sensitivity analysis indicating "4% change in chiller efficiency makes very small change in overall energy use whereas reducing the operating hours by one hour per day provides 8% reduction and weekend shutdown reduced energy by 19%". There is also a sensitivity analysis of comparison between of annual consumption compared to weather data (UK) and operating hours.

CarbonBuzz
CIBSE, with RIBA (Architects) and other partners, have developed a website-based CarbonBuzz tool (CarbonBuzz 2015) as a practical tool for designers to compare their low energy designs against others on the website. This tool, based on CIBSE TM46 methodology, is used to compare buildings to whole of building.

This tool allows online input of design and actual annual energy consumption.

The online tool uses the input data to be converted to carbon emissions and then allows comparison with emissions for other whole of buildings in the data base, and with CIBSE benchmarks.

For tertiary education, whole building comparison is not useful. The CarbonBuzz methodology does not currently include the significant occupational criteria affecting energy consumption or hours of operation.

Tools for comparing design and actual energy use

The CarbonBuzz tool from CIBSE (CarbonBuzz 2015) seeks to support the industry in its drive to manage the energy use and CO_2 emissions from buildings, and help architects and engineers to close the gap between design energy use and actual energy use.

The analysis of CarbonBuzz by Ruyssevelt (2014) provides a more useful insight into the use and results of this comprehensive program. The platform allows users to compare design energy use with actual energy use side by side to help users close the design and operational energy performance gap in buildings. Quantitative benchmarks are published in building categories including universities.

Whole of building benchmarks show the 'design to actual' performance gap with median results. For electrical only and electrical and other energy sources, energy use ranges between actual 163 and 154 kWh/m² pa, compared to design 67 and 64 kWh/m² pa, over samples of 13 (design) to 40 (actual) buildings.

In reviewing benchmarking progress and rigour**,** Hyde et al. (2007) cite discussion with Dr Paul Bannister (p. 199-200) that "fixed benchmarks are derived from statistics on a large cohort of buildings, but tailored benchmarks are customised to take into account special circumstances in buildings and to assist in finding more detailed information on the buildings (Cohen et al. 2007)".

Building energy quotient in the USA

The building energy quotient program, known as bEQ, by the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) was designed to augment and complement other rating programs such as LEED. The difference is the building energy quotient focuses exclusively on energy and requires an in operation assessment that includes an ASHRAE level 1 energy audit. Figure 8 is an illustration of the building energy quotient process.

Figure 8 Illustration of the building energy quotient process rating tool methodology

Source: www.buildingenergyquotient.org/

As reported by Montgomery and Wentz (2014, p. 64) in the ASHRAE journal:

> ASHRAE'S Building Energy Quotient (bEQ) program is a voluntary rating program that applies an easily understood scale to compare or benchmark, a building's energy use to similar buildings in similar climate zones. Two independent rating systems exist within bEQ; in operation and as designed. The in operation rating uses actual, metered energy consumption and evaluates how the building was design, constructed and operated. The as designed rating uses an energy model that evaluates the buildings envelope and systems. The model uses standardized operational and occupancy variables to create a more reliable and comparable model that creates a consistent, accurate evaluation of a buildings physical characteristics and HVAC system.
>
> The calculated value for both in operation and as designed is simple and straightforward. In each case the EUI of the building, either actual or modelled, is divided by the median EUI table found in the bEQ workbooks. The EUIs are derived using the methodologies and tables found in ASHRAE Standard 100's proposed 2014 revisions. The EUI in each case is converted to source EUI using industry standard conversion tables to ensure a consistent comparable result across building types and climate zones. The bEQ rating score is calculated by dividing the EUI(candidate building) by the EUI (median) and multiplying that product by 100.

EUI is the acronym for Energy Use Intensity. This is a benchmark measured in (USA) kBtu/sqft-yr, defined by the CBEC commercial buildings energy consumption survey and data base for building energy consumption use across multiple climate zones and building types.

Recent updates to bEQ, version V.7a, August 2014 improve the tool. ASHRAE uses methodology from Standard 100-2015 Energy Efficiency In Existing Buildings to calculate the rating. This methodology allows generation of normalised median energy unit intensities for all building types covered in the Commercial Building Energy Consumption survey. Energy use intensity is calculated by dividing the building annual energy use by its gross floor area.

The output of this comprehensive program is designed for whole of buildings to provide qualitative ratings 'inefficient' to 'very good' based on an ASHRAE accredited building audit, depending on comparison with a database of existing survey results. This program is not designed for functional area campus buildings and does not provide any quantitative benchmarking.

Energy Star

The Energy Star energy benchmarking rating tool Portfolio Manager was introduced by the US Environmental Protection Agency over 15 years ago. The methodology is based on comparing the subject building energy use intensity with some selected energy use intensities from the Commercial Building Energy Consumption survey data from the US Department of Energy, established and collecting data since 1989. The Commercial Building Energy Consumption survey (CBECS) (ref. appendix 6D) identifies 20 different building types over five climate zones to allow a selection to attempt some match with the subject building. The comparison of energy use intensity for the subject building with the selected sample on the Commercial Building Energy Consumption database provides a score or index from 1 to 100 which represents a building percentile energy efficiency compared to a similar building nationally. The key issue is how similar are the compared buildings.

2.5 Energy audits for benchmarking

Resources on conducting an energy audit are reviewed, starting with the Australian Standard for Energy Audits in Commercial Buildings.

2.5.1 Australian Standard for energy audits in commercial buildings

There is an Australian Standard for Energy Audits in Commercial Buildings, known as AS/NZS 3598.1 (Standards Australia 2013), which notes that:

> Energy audits and surveys are investigations of energy use in a defined area of site. They enable an identification of energy use and costs form which energy cost and consumption measures can be implemented and reviewed.

This standard is a process document without detailed information as to 'how to' other than it is based on assumed availability of utility metered data and references the CIBSE energy audit and survey documentation (CIBSE 2013).

Section 4.11 defines benchmarking as "the use of energy performance indicators to compare the energy use of the site under review with similar sized sites performing the same function and, thus establishing whether energy consumption is high, reasonable or clear efficient".

Section 13.1 on audit requirements includes consideration of issues all included in the LLO process with the exception of recommendation of energy efficiency measures, which is not within the scope of this research as this research focuses on where the energy efficiency measures may be applied, not what measures should be adopted.

In 2010, Australian and New Zealand governments sought a review of the 2000 AS3598 publication. This review was conducted by University of NSW and Energetics, published as a consultation report *Revision of AS/NZS3598 Energy Audits (*University of NSW and Energetics 2011.) The respondents to the review process debated the issue of whether the audit standard should focus on industry sector (type of use) or technology (type of systems or equipment). The review reported the majority recommended a focus on technology and how the audit process could lead to identifying improvement, leaving industry sectors (differing groups and associations) to develop their own guidelines.

Benchmarking approaches for building assessment tools

Hyde et al. (2007) reviewed benchmarking approaches for building assessment tools and identified the issues in evaluation of building environment assessment tools and states in the abstract of the paper: "at the heart of these tools is a benchmarking approach which assists in setting environmental standard" and defines functional benchmarking as **"**the aim of this type of benchmarking is to investigate the performance of core processes, functions and activities in the building" (in this case energy consumption).

Hyde et al. (2007) reference four steps to benchmarking:

- *Scoping*: identify what to benchmark, then gain support from management and identify projects to be benchmarked.
- *Data collection*: decide on methods of collection including contacts with benchmarking projects.
- *Analysis*: establish whether a performance gap exists and communicate findings.
- *Implementation*: gain support for benchmarking action plans, measure performance and recalibrate benchmarks.

Hyde et al. (2007) introduced the concept of triangulation, using information from a number of sources to support or negate the benchmark.

Hyde et al. (2007) concluded that "very often highly rigorous (BEA) tools are data hungry and expensive to service, making them impractical to use in the schema of organisations. As rigour is traded against practicality of use, many tools include a checklist for pre-assessment". There is a need to provide an accessible cost effective tool to assist in the comparative energy rating, by benchmarking, of campus building functional areas to thence, whole of building comparisons.

2.5.2 Resources and tools for energy audits

There are several tools and resources for conducting energy audits including Beggs (2009), Thumann (2010) and Al-Shemmeri (2011). These are reviewed.

Energy audits for energy management in buildings

Al-Shemmari (2011) concludes, as does Beggs (2009), that normalised performance indicator is an overall criterion for consumption of energy indicating how the building compares with others. The treatment focuses on building space heating, with little attention to internal equipment, plug in or otherwise.

Al-Shemmari (2011) provides extensive worked examples for energy use, management and consumption in buildings. Once again, there is the implicit assumption that the use represents whole of building. There is no mention of functional areas or their use to aggregate into whole of multi occupancy building.

Financial costs

Beggs (2009) is a comprehensive publication which includes financial analysis and cost information not usually presented. His analysis is based on dividing the utility billed over time and over type of (whole building) use.

Beggs (2009) presents normalised performance indicators from CIBSE data. No treatment of functional areas is provided, only whole of building, and it assumes the buildings are single use. However, a useful explanation of time dependent energy analysis is provided. In the chapter on estimating energy use, the example given is a fairly simple product of time of use and upper level plant power, which is not accurate or realistic.

Multi building energy audits

In discussing multi building energy audits, Knapp (2006, p. 1) notes that:

> Traditionally, these audits are similar to a batch manufacturing process in that a host of measurements are taken across all buildings, and then various analyses are performed.
>
> ...Collecting and analysing data for a host of buildings all at once allows mistakes to be repeated.
>
> By handling the data building by building, common mistakes... are avoided.
>
> Lean auditing addresses this problem.... more quickly.

This is the energy audit process used in the research methodology for this thesis.

Resources for energy audits

Thumann et al.'s (2009) *Handbook of Energy Audits* is not a comprehensive check review of the energy audit process, including economic evaluation, self evaluating checklists for building fabric and services, but it does have a very useful compendium of handy working aids, various work sheets and check lists. A major omission is that while the work sheets provide for input for hours of operation, normal and after hours, they do not provide for a correction to equipment name plate ratings to account for the running at part load with variable efficiencies.

Non domestic energy benchmarks and benchmarking methodologies

The research presented by Liddiard et al. (2008) is part of the major four year research Carbon in Buildings (Carb) involving a consortium of five UK universities. Various international energy benchmarking models in non domestic buildings were reviewed. Liddiard et al. (2008) write:

> The energy performance of a non-domestic building is frequently quantified by judging its performance against that of a sample of other similar buildings, usually through the application of a benchmark calculated from the sample.

These models usually take the form of an energy use intensity. Energy use intensity is commonly referenced as kilowatt hours per square metre per year (kWh/m² pa) or similar.

Liddiard et al. (2008) then analyse and comment on the major benchmarking methodologies, as identified under the following headings ECON19, ECON75 and TM22 (UK), APEC (Asia-Pacific) and Energy Star (US), summarised below.

UK

ECON19 by Carbon Trust is an assessment of energy performance of office buildings, providing benchmarks for various building types and uses; based on surveys in the 1990s, using the distribution model, medians and percentile. Note that these benchmarks are for whole of office building and are divided into two categories:

- Typical, with energy consumption patterns which are consistent with median values of data collected in the mid-1990s for the Department of the Environment, Transport and the Regions from a broad range of occupied buildings.
- Good practice, with examples in which significantly lower energy consumption has been achieved using widely available and well-proven energy-efficient features and management practices. These examples fall within the lower quartile of the data collected.

ECON75 by Carbon Trust provides some disaggregated data on energy use from diverse building use and classifications. Note that this data is difficult to source.

TM22 Energy Assessment and Reporting Method by CIBSE (2006) is a very comprehensive analysis tool and allows via a software package, comparisons between a subject building, against established benchmarks from ECON 19 (Carbon Trust 2015). Various building and system sub types are included (not including university campus).

This method has two assessment types. Type (a) for whole of buildings, and type (b) which accommodates differing types and uses within a building. The specific end users and special energy users include some building types common to campus buildings; catering kitchen, computer room, sports facilities and various equipment energy use types, cooling, office equipment and others. However, these are not a typical campus set of functional areas. Equipment type applies to the whole of building. The output of the analyses are TM22 'AGT' a measure of performance which compares the actual against two benchmarks 'good practice' and 'typical'.

Asia-Pacific

The Asia Pacific Cooperation (APEC) energy benchmark system provides gigajoules/m² pa for offices and other building types (no campus buildings) by online submission into a public access database. The benchmarking process is achieved by comparing the test buildings gigajoules/m² pa against similar buildings in the database.

US

Energy Star is an assessment and benchmarking system from the US Environmental Protection Agency. The system is based on the Commercial Building Energy Consumption survey done every four years, covering 4,000 buildings in 2003. The basic survey is done over the phone. The vast amount of data is processed by weighted regression analysis providing an index of energy use intensity with the index calculated from 1 to 100. A score of 50 is average. This process compares a subject office building against a total sample benchmark, referenced as 'empirical benchmarking'. Technology factors are not included in the analysis.

Liddiard et al. (2008) suggest "to avoid problems of data collection and sample size associated with empirical benchmarks, it is possible to use an alternative model based benchmark. Such benchmarks are usually associated with specific building activities".

Further Liddiard et al. (2008) discuss in detail the potential problems with energy benchmarks including sample size, statistical analysis and data collection, with reference to the methodologies described above and conclude that "whichever methodology is used, the quantity, quality and auditable source of and benchmark's data are of importance. There appears to be a general lack of data transparency in a number of empirical benchmarks... a possible exception to this situation is a model based benchmark, which can be applied to an individual building according to local design restrictions".

Schofield (2014) makes a very robust criticism of the US Energy Star methodology, with a principal criticism being the lack of operational data, called 'technology factors', which affects the resulting performance index and therefore any valid comparison between buildings.

This thesis research uses the LLO tool modelled common functional areas to provide a benchmark for comparison. This is the philosophy behind the LLO tool functional areas developed in this thesis.

2.5.3 Energy efficiency in buildings – international best practice

International best practice resources include CIBSE's *Guide F: Energy Efficiency in Buildings* (2012) and ASHRAE's *Energy Efficiency in Existing Buildings* (2015) and ASHRAE 90.1..

Guide F: Energy Efficiency in Buildings from the Chartered Institute of Building Services Engineers (2012) is also recognised as international best practice, a most comprehensive and practical document relating to energy efficiency in buildings. There are several chapters which relate to this research including benchmarks.

Chapter 18, read in conjunction with their Appendix 18. A1 (site survey checklist) and the upgraded methodology in TM54 (CIBSE 2013), describes energy surveys, audits and assessment of energy saving measures. The LLO campus energy audit program designed for and used in this research is consistent with the documentation. This site survey check list (18.A1) is the most comprehensive list seen to date and more comprehensive than used in most energy audits and surveys, due to the time usually available to complete the activity. Chapter 19 concentrates on using and interpreting utility based energy consumption data, with advice on setting targets.

Guide F references TM22 (CIBSE 2006), based on providing an assessment of energy performance of an occupied building based on utility metered energy input and various building and energy consuming system characteristics, compared to existing CIBSE TM46 database and ECON19 collated for the purpose of compliance with display energy certificates legislation. The output is a comparison of estimated or calculated energy consumption against various benchmarks.

This TM22 methodology appears most comprehensive allowing the use of optimum b analysis of a multi zone building with specific uses. The output or results are presented as 'whole building' which includes any multi zone or special areas.

The problems with using the TM22 methodology for Australian campus buildings are the UK TM46/ECON19 data is climate, energy and use specific and not applicable to most Australian conditions. Any TM22 whole of building comparison runs the risk of showing a similar outcome while the large differences in 'special uses' which the LLO tool terms 'functional areas' can cancel each other out, leaving no useful information as to the individual functional area's relative energy efficiency, obscuring the areas for energy consumption improvement.

There is nothing in this method which provides disaggregated data, fundamental to the LLO research and to allowing valid comparison between campus multi use (functional areas) buildings.

The *Guide F* methodology does not add to the gap in the knowledge. However, there may be scope for some modification to the software and data entry to have a modified application of TM22, useful in the Australian context. This is a topic for further study, with the full co-operation of CIBSE.

In Chapter 20 (CIBSE 2012, p. 20-1), the benchmark data is quoted as:

> All known UK energy and component benchmarks available at the time of publication (March 2012). These benchmarks date back to the 1998 edition of the guide and some of the primary source publications are no longer available. However they represent the best information currently available.

The energy benchmarks are presented as kWh/m² pa for a wide variety of building uses showing good practice and typical practice, with some references to education (further and higher), for fossil fuels and electrical shown separately. This is very useful information. The electricity consumption could be used in the Australian context after correction for climate and documented operational issues.

2.6 Summary and conclusion

This chapter reviewed the literature and data on energy use in commercial buildings in particular to identify the gaps in knowledge and practice relevant for the tertiary education sector from commercial buildings.

The literature review showed that some form of energy benchmarking is used to compare normalised energy consumption (kWh/m² pa) for commercial buildings. This may be at the design stage, design estimated (or modelled) compared to actual achieved (measured by utility bills). However, design or modelled assumptions do not correspond with the actual building use for several reasons:

- differences between 'design' and 'as built'
- difference in buildings – facade materials, insulation, sealing, quality of building and finishes
- differences in services – equipment efficiency, commissioning, quality of installation
- differences in operations – hours of operation, fit out variations to building or services, occupancy density and use.

Benchmarking may also be undertaken after building completion, at the operational stage, year on year of operation, with the possible scenarios including comparisons with similar buildings, comparison with same building year on year, and comparisons with industry benchmarks.

A key issue which affects the accuracy of comparing energy efficiency between buildings is determining what constitutes a similar building. Buildings may vary by facade, services, hours of operation, energy density, method of use, lettable areas, locality and climate, principal use of the building, year on year (same building), changes to tenancies, layout, operations, energy densities, and maintenance to equipment.

For industry benchmarks, the issue is what benchmark to use. In Australia, the NABERS energy rating scheme has wide acceptance by the property industry and regulators. The criteria for comparison are relatively simple:

- area (gross floor area)
- number of computers (as a measure of occupancy)
- hours of operation (with a defined occupancy)
- postcode (for location, ambient conditions)
- energy consumption (utility bills).

The success of the NABERS scheme is due to the very strict criteria for collection of data for the application of the NABERS rating and the rigorous training and, after training, independent auditing of the assessors, together with an algorithm validated over many years of experience.

In the USA, Spielvogel (2015) and Schofield (2014) strongly criticise the Commercial Building Energy Consumption survey which has been conducted every 4-5 years since 1989. This survey supports a database estimated at over many thousands of buildings, from which the Energy Star and building energy quotient benchmarking systems draw information to provide their comparison ratings, that is, to scope a subject building against this national database. Spielvogel (2015) and Schofield (2014) base their criticism of these national energy rating schemes on the following:

- lack of training of the assessors to provide online or over the phone information
- the difficulty (as noted by Schofield) in matching the significant characteristics of the building to be benchmarked against any similar building in the database.

Various multivariant linear regression analysis can be applied to all the Commercial Building Energy office buildings to determine the extent to which the recorded database variables affect energy use. The resulting regression coefficients can be applied to predict the energy use of a hypothetical building, with characteristics similar to those of the one being benchmarked. But this is a time consuming process and is very dependent on the quality of input and leaves room for discussion concerning the accuracy of the output.

The UK has a similar narrative. CIBSE (2011) critiques the use of the display energy certificates, covering 45,000 buildings, certified up to 2010, in accordance with the TM46 classification and methodology. UCL Energy Institute and TM54 Evaluating Operation Energy Performance of Building at the Design Stage (CIBSE 2013) highlight the following issues and requirements for increased accuracy and usability of energy benchmarks. This critique is summarised by Bruhns et al. (2011, p. 37):

> Technical benchmarks – work is necessary to develop a technical approach to underpinning benchmarks for all building types and categories in order to understand how the energy demands of representative (iconic) buildings of their particular type are built up from specific end-uses and what realistic expectations should be for Best Practice, and perhaps for Advanced Practice. This would provide a clearer picture of what A and B rated buildings might be aiming for, i.e. what buildings should use rather than what they actually use. This work would also help identify separables and occupancy adjustments more clearly, and could perhaps be used to create Tailored Benchmarks which are more precisely related to a particular building, its equipment and use.

The literature reviews identifies problems with existing energy benchmarking tools which are incorporated into the development and design of the LLO tool as appropriate to tertiary campus buildings. The LLO tool addresses these issues by including:

- dynamic simulation modelling (with weather data files) rather than steady state calculation
- structured interviews with occupiers
- corrections to equipment nominal ratings for realistic power consumption data inputs based on actual use estimates
- presentation of annualised energy consumption results in the form of a range low to high, poor, typical, good practice
- results presentation with an indication of key assumptions and sensitivity to the independent variables
- the use of benchmarks underpinned by identification of end use, separate from whole of buildings, for mixed use buildings.

There does not appear in the literature, a process to assist with the gap in the knowledge of this research.

The following chapter discusses energy use and benchmarking in tertiary education buildings, as a subset of commercial buildings.

3 Literature review: energy in tertiary education buildings

3.1 Introduction

This chapter reviews literature and data on energy use in tertiary education buildings overseas, in Australia and at the University of Sydney to identify gaps in knowledge and practice.

3.2 Energy in tertiary education buildings in the UK, US and Europe

There are several resources on energy use in tertiary education buildings in the United Kingdom, United States and Europe.

Higher education in the UK refers to academic institutions offering qualifications beyond the General Certificate of Education (**GCE**) Ordinary Level. The university campuses study does not include colleges of higher education.

3.2.1 United Kingdom

The report *Sector Review of Higher Education Energy Consumption in the UK* by Ward et al. (2008) from the University of Sheffield (2008) examined key energy consumption characteristics of the UK higher education institutions to identify patterns, trends as well as areas and issues requiring further investigation. This high level review covers 103 UK university campuses with data drawn from Higher Education Funding Council Estate Management Statistics 2001 to 2006.

Useful information from this study is that gas remains the primary energy source for the sector accounting for 53.5% of total energy consumption in 2006. In comparison, the *Energy Savings Action Plan* (University of Sydney 2008, p. 31) indicates gas is less than 18% of the total energy source for the University of Sydney.

The universities are classified with range of energy consumption gross internal area:

- ancient universities 330 kWh/m²
- red brick universities 297 kWh/m²
- institutes and special colleges 339 kWh/m²
- plate glass universities 318 kWh/m²
- new universities 259 kWh/m²
- colleges of higher education 240 kWh/m².

Not surprisingly, the analysis data shows strong levels of correlation between numbers of students, and building area and research activity to energy consumption. The analysis shows weak correlation between age of the building and total energy consumption.

The author notes that also indicated is a lack of sensitivity to facade variations.

Ward et al. (2008, p. 2949) note:

> There is need for change in the existing energy reporting format to provide disaggregated energy statistics that capture end use consumption levels and patterns. It is essential that information about energy consumption in the sector contains data at a sufficient level of detail to inform

> interventions as well as aid auditing and effective benchmarking. To achieve such levels of data will invariably require sub metering and may incur significant cost to the institutions.

This again points to the gap in the knowledge of no information for functional areas.

The Higher Education Environmental Improvement (HEEPI) organisation completed a benchmarking exercise on energy consumption of selected buildings in universities and colleges over the period 2002 to 2004. Data was collected from over 30 universities for 223 buildings.

HEEPI (2006) provides insights into the methods used to formulate the published tables with the final HEEPI benchmark categories. HEEPI lists typical early performance benchmarks for electricity as kWh/m² pa. It is noted these UK benchmarks from HEEPI (2006) differ markedly from CIBSE's *Guide F* (2012). HEEPI methodology included eliminating non typical buildings and final results are from 163 buildings, grouped into nine categories, depending on building use. No normalisation was applied for degree day region, occupancy or building mass and exposure, nor was there any distinction between naturally ventilated or air conditioned buildings. It is a very useful comparison with national yardsticks from Carbon Trust publications.

For comparison with Australian benchmarks, the following issues must be taken into account:

- differing energy source supply proportion in the UK: gas versus electricity
- differing building variables considered
- differing operation issues considered.

The buildings appear to have been selected not as mixed use, but assumed whole of building as principal use, so aside from the above criteria differences, the whole of selected buildings could be considered functional areas.

It is particularly significant that the HEEPI (2006) describes a workshop to discuss the benchmarking between the facilities managers, who are likely to have a good understanding of the building and its operations, which should contribute to useful benchmarks, for comparison with similar buildings on other campus sites.

University College London completed a review in October 2014, which appears to include approximately 50 university campus buildings, to indicate the performance gap between design and actual for electricity and non electricity use as a percentage of consumption. The mean design was approximately 65-59%, based on 13 buildings and the mean actual was approximately 163-154% based on 40 buildings.

Hong's (2015) PhD thesis *Benchmarking the energy performance of the UK non-domestic stock: a schools case study* is a comprehensive review and critical appraisal of the CIBSE TM46 display energy certificate protocols for energy consumption in a wide range of buildings, including schools and university buildings. The TM46 process is reviewed by Bruhns et al. (2011).

Hong (2015) concentrates on school buildings which, although a different subset from universities in terms of architecture, do have energy reporting issues in common. Hong reports the results highlight two key issues associated with the (schools) classification system: inappropriate levels of aggregations and misclassification of buildings. This comment supports the conclusion of this thesis regarding disaggregation of buildings into functional areas.

Hong reviews using multivariate regression analysis, the relationship between various physical building features and operational characteristics that have significant correlations with patterns of energy use of primary and secondary schools. Key findings of the analysis are both physical and operational characteristics need to be taken into account for improved benchmarking. Note that the LLO tool has both of these principal types of characteristics.

Hong conducts post occupancy evaluations of nine modern secondary schools, including energy end use analysis, data from CIBSE TM22 methodology, and including sub metering and site visits. Hong concludes (2015, p. 228) "the main objectives of this chapter were to assess the disaggregated energy consumption of schools and to observe the relationship between intrinsic features of school buildings and energy use consumptions".

It is surprising that this research needs multiple regression analysis to show what variables, including building "intrinsic" characteristics as well as operational equipment, system and end use energy issues are significant in establishing energy consumption leading to useful energy benchmarks. The CIBSE TM22 methodology (referenced by Hong) and multiple publications from ASHRAE and CIBSE regarding building energy modelling make the independent variables and their relationship very clear.

Hong concludes (2015, p. 238) "adopting hybrid approach for benchmarking in UK non domestic stock is likely to be difficult and costly, without adopting a hybrid approach. Benchmarking practice in the UK will continue to lack robustness in assessing operational efficiency".

The Carbon Trust sector overview (March 2012) *Further and Higher Education* provides generic advice for energy saving opportunities to existing facilities in the UK and many case study examples are presented, but the context is UK weather related. It notes (p. 29) that "installing sub-meters in each department and re-charging them for energy used can be a great motivator to reduce costs". Useful action check lists (p. 33-34), understanding your energy use (p. 35) and the general thrust of the paper support the concept of functional area benchmarking, with no data, but simple processes outlined.

3.2.2 United States

In the United States, there are two organisations involved in collecting university and college campus energy (and other sustainability) data: Leadership in Educational Facilities (Association of Physical Plant Administrators) and the Association for the Advancement of Sustainability in Higher Education.

Both of these organisations collect data from web based forms, collate the date, develop energy use intensity which is the favoured metric calculated by dividing the energy use by total gross area. These energy use intensity metrics are then compared to the national Commercial Building Energy Consumption survey database to provide a comparison for a whole of campus or possibly an individual building.

It is very difficult to interrogate the Commercial Building Energy Consumption database for useful comparison between widely differing buildings. No data is available from these sources to ‘close the gap’.

3.2.3 Europe

Escriva-Escriva et al. (2011) present a new (claimed) energy performance index, energy rating factor, “to provide indices for performing energy characterisation and classification of buildings as part of a complete and accurate method that does not require extensive information”.

The index is based on EU country regulations, Spain, Italy and Greece for example, focus on the energy behaviour of buildings and only in terms of $C0_2$ emissions, disregarding some other important energy parameters. “Comparison against reference levels is made using validated software programs that are usually cumbersome and applied during the design phase.”

The energy rating factor is derived from dividing the overall energy consumption by the product of the building exterior surface, multiplied by the hours of operation, monthly (2011, p. 478). This is obviously an operational rating, relying on actual consumption, with the total fabric area as the individual building descriptor. This is unusual, as most rating systems normalise on floor area, with possibly some factor for facade thermal efficiency.

Additionally, the overall consumption is adjusted by a series of weighted factors based on various operational criteria, hours of use, numbers of users, air conditioning and extent of use. In conclusion, Escriva-Escriva et al. (2011) claimed “the building rating method presented has advantages over commercial software because it enables monthly monitoring of buildings during the use stage”.

3.3 Energy in tertiary education buildings in Australia

In 2009, university buildings accounted for around 6% of the net lettable area of all commercial buildings and consumed about 5% of the commercial building sector energy (*Baseline Energy*, Department of Climate Change and Energy Efficiency 2012). These proportions are projected to grow by 2020 to 7% of total area of all commercial buildings in Australia and 6% of total energy consumption.

3.3.1 Group of Eight and TEFMA

The Group of Eight Universities, representing eight of the major universities in Australia, characterised by significant research income, established the Tertiary Education Facilities Managers Association (TEFMA) which is the comprehensive source of information on tertiary education buildings in Australia. TEFMA has collected data from Australasian universities since the 1990s, across a range of operational cost categories, one of which is annual energy use, and the results are given in a range of averages such as per square metre, and per effective full-time student unit. The problem with these benchmarks is that the aggregation of campus data does not compare use, since a campus in the city can have a much denser campus than a greenfield campus. Consequently the benchmarks established are of indeterminate error.

G08 survey into building energy consumption by building type – concept comparison

Since 2013, TEFMA has identified 'general purpose' and 'energy intensive' buildings.

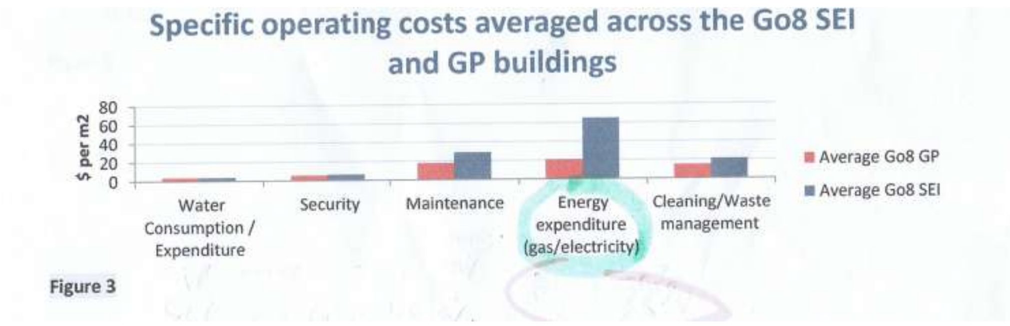
The G08 Group defines (ref. Group of Eight background report Oct 2014) "service and equipment intensive " (SEI) as campus building space maintained for research intensive activity, requiring costly build and operations, typically medical, biological, chemical life science. "General purpose buildings" (GP) do not require the high energy intensity equipment of build cost, typically administration, economics, law.

This is the only attempt to examine energy benchmarks in a more detailed way than whole of building. The G08 universities attract significant research income compared to other universities in this tertiary sector and have conducted a survey (Kuzcek 2014) related to space, energy and other issues, comparing general purpose buildings to services and equipment intensive buildings. The purpose of the survey was to establish services and equipment intensive cost and space metrics for forward planning and to identify issues relating to research activities, which require services and equipment intensive buildings.

The report *Research Space within the G08, Extent and Costs?* (Kuzcek 2014) (in part confidential) summary (TEFMA 2014, p. 3) notes that it:

> points to the inherent risk in using broad averages (i.e. TEFMA sector averages) and to some extent campus averages, which can mask actual costs of specialist infrastructure maintained across the G08 universities.

Energy consumption data from this report includes comparative energy use across the G08 universities, between general purpose and service and equipment intensive type of buildings, as shown in Figure 9. Energy expenditure (gas and electricity) accounts for approximately 30% of specific operating costs in general purpose buildings and 50% in service and equipment intensive buildings.



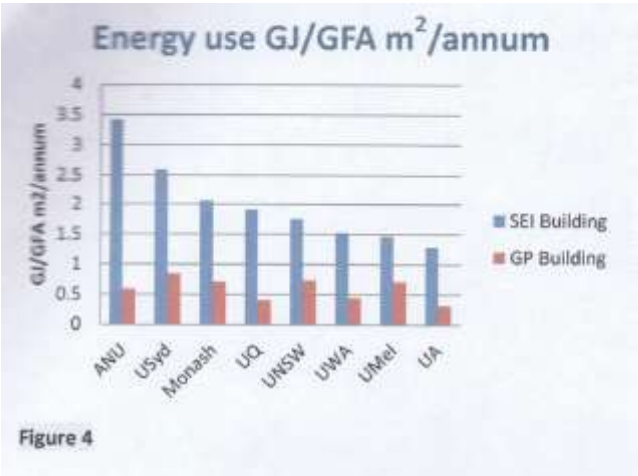


Figure 9 Energy use by building type: general purpose and service and equipment intensive
Source: Kuzcek (2014, p. 4-5).

Kuzcek (2014) reports this shows average consumption of general purpose buildings was 0.6 gigajoules/m² (gross floor area) pa which aligns closely with the consumption figure of 0.74 gigajoules/m² (gross floor area) pa for whole Australian sector for all buildings as reported in the TEFMA 2012 survey data. Energy consumption totals for the G08 service and equipment intensive buildings were on average 3.3 times higher (at 2.0 gigajoules/m² pa) than general purpose buildings. Note that 0.6 gigajoules/m² (gross floor area) pa is equivalent to 205 kWh/m² (gross floor area) pa. Also noted in this report (Kuzcek 2014) is that service and equipment type space contributes between 15-24% of usable floor area campus wide across the G08 universities.

Correspondence with G08 campus facilities on space and building energy data

Following attendance at the annual Tertiary Education Facilities Managers Association conference in 2010 and 2015, liaison with the current TEFMA president elect, Steve Sullivan, and the University of Sydney manager of energy and sustainability Nav Brah, contacts were provided and made with the G08 facilities managers involved with energy. From those who responded to inquiries it is clear that 'whole of building' data for energy consumption is generally available, but a breakdown into room or functional area is not.

The following information was requested from G08 members by the author:

1.Whole of campus and likely individual building energy utility consumption data normalised to kWh/m^2 (usable floor area pa. Is this electricity and gas, and are these figures available separately?

2. As for the University of Sydney, data similar to (Campus Infrastructure Services) a split up of GJ/GFA m^2 pa energy use for SEI and GP buildings.

3. Any sub metering (or energy audit or other sources) of energy (electricity, gas or both) for common functional or academic areas, within your differing mixed use buildings, or room as per the G08 space, data user guide.

eg

1 offices

2 teaching

3 specialised teaching and research

4 ancillary

5 library and informal learning

6 general faculty.

or

any data down to rooms level such as:

628/629 central or local computing

403 workshop

202 lecture theatres over 100 seats

310 computer labs - open access

The followings responses were received from G08 and other universities.

G08 universities

University of NSW (Nicholas Jones) provided individual building data, not discreet functional spaces and they are interested in this research.

University of Western Australia (Geraldine Tan) reported that the main campus accounting for 80% of buildings, has individual metered data, and the campus has a central chilled water plant.

Monash University (Paul Barton) reported this campus has individual building data, is willing to share data and assist in research, and additionally, based on gross floor area, the energy share has been allocated across G08 room codes. There are no sub meters.

University of Sydney (Nav Brah) reported generally whole of building data available, and further interest in this project is indicated. The Campus Infrastructure Services office has fully supported and facilitated the energy audit as part of the graduate subject DESC9111 since 2009.

University of Adelaide (Libby Dowling) reported individual building electrical consumption for one of four campuses, but no building level metering for gas at any campus.

University of Queensland (Andrew Wilson) reported rolling out energy efficiency measures based on numerical and human elements. They do not see value in the LLO tool.

Other universities

Australian National University (Dr Su-Wild River) indicated that there is individual buildings consumption data, and they use sub metering. They have the potential for functional area reporting, but have not done to date. They are interested in benchmarking as a management tool.

University of Western Sydney (Lyn Anderson) commented on the diversity of buildings spread over 10 campus sites, including heritage listed. A smart meter pilot has been commenced at one campus but it is too early to discuss results.

University of Technology Sydney (John Kraefft) replied that they only have energy consumption at whole of building level, but that they have a sub metering installation in progress to allow more detailed energy mapping. He also commented that having a central cooling and heating plant presents a challenge for metering energy to functional areas across multiple buildings.

Macquarie University (John Macris) has a most comprehensive program included the installation of multiple sub meters and sensor recorders and the matching software programs to capture and report data relating to energy consumption and other characteristics, reported by Esmore (2015). It included an audit of 50 buildings, over 200,000 m². When the installation is complete, a wide range of data will be available for the new Tableau platform. John Macris has supplied copies of three building audits, completed in 2014, in accordance with AS/NZS 3598.2000.

It appears from the G08 facilities managers' responses that whole of building energy consumption is available, but apart from the general purpose and service intensive building type survey, similar campus building energy benchmarks are not being used, let alone the more accurate functional area benchmarking comparison. This is due to lack of resources and other activities. A typical helpful responses came from Paul Barton of Monash University, Nicholas Jones of University of NSW and Nav Brah of University of Sydney who provided the campus whole of building energy consumption information. Their reply, in common with typical university campus administrations, expresses interest in the 'functional area' concept, but indicates they appear not to have the resources to develop this to the next level.

3.3.2 Green Star Education V1 rating tool

The Green Star Education V1 Rating Tool "has been developed to assess environmental attributes of new and refurbished educational facilities in Australia" (Green Building Council of Australia 2010, p. A). The methodology of this tool relies on comparison of a predicted energy consumption of an educational facility by computer modelling with a calculated benchmark. However energy modelling has its issues as referenced in TM54 *Evaluation Operation Energy Performance of Buildings at the Design Stage* (CIBSE 2013). Consistent results require considerable appropriate professional training.

Setting aside the discussion of the accuracy of energy modelling, particularly of existing campus buildings, with the difficulty of collecting relevant data, the skills involved in building modelling cannot be expected to be readily available in the average building manager. Hence there is a need for a straightforward energy rating consumption tool.

The Green Star Education V1 standard benchmark summary, in particular its Table 1 Education Facility Energy Benchmarks by Space Type, provides useful guideline data for university buildings, reported as having been collected from 19 educational facilities, by survey to facilities managers (Green Building Council of Australia 2009). The Green Star survey benchmark information and comparison with the DESC9111 audited data is reported later in Chapter 3.

The Green Star benchmarks for university buildings are useful, but the methodology for benchmarks for estimation, including as typical, water cooled chiller and gas boiler and high performance glazing, differs from the author's experience with buildings from the University of Sydney audit study. The purpose of the Green Star Education V1 benchmarks is to provide a measure to establish overall sustainability rating by modelling against the benchmarks.

3.4 Energy use at the University of Sydney

There are several sources of information about energy use at the University of Sydney. Key sources of information and data were sought from personnel at the University of Sydney Campus Infrastructure Services. A great deal of personal communication has taken place between utilities officer, David Latimer (no longer with the University of Sydney) and the subsequent staff, currently Rose Chaaya. These sources were able to make available building energy consumption data for the University of Sydney and other Australian universities sourced from TEFMA.

3.4.1 Energy savings action plan

A key source on energy use at the University of Sydney is the *Energy Savings Action Plan. The Plan* wa*s* authorised in 2008 by the Vice Chancellor's office to satisfy NSW government requirements by providing a level 3 AS/NZS 3598:2000 technical audit and review of 14 significant buildings, representing 40% of the campus gross floor area. It was conducted by Emet Consulting. This study was based on 2006 to 2007 historical utility data, as provided from the campus utility information system, which records and apportions utility metered information to individual buildings, together with Emet Consulting's use of IBER and EMM proprietary energy modelling software.

The *Energy Savings Action Plan* (University of Sydney 2008) provides whole of building energy consumption for buildings widely differing in architecture, use and services, showing energy intensity varying between 112 and 3,387 kWh/m² gross floor area. Although useful breakdown figures are presented on use by application and by time of day, there is no attempt to use the "power of comparison" to indicate good or poor practice between these 14 buildings.

The 'average' energy benchmark consumption over all these 14 buildings is estimated at 208 kWh/m² gross floor area for electricity and gas, a useful benchmark in itself. But due to the diversity of use, architecture and services it does not lead to any action plan or identification of where to start a program of energy reduction for any individual building.

This authoritative and useful work typifies the gap in the knowledge problem. The knowledge is available at a fairly low level. The identification of energy saving potential related to building services, mechanical and electrical (principally heating ventilation and air conditioning, and lighting), in each building with project costs and benefits were identified. This analysis was carried out by actual survey, and projected savings of 4.4% at the end of the project completion. The opportunity for building or faculty management to compare and recommend between their diversified buildings was missed.

The energy saving measures recommended in the *Energy Savings Action Plan* for services in various buildings are standard industry practice, such as those in CIBSE’s *Guide F* (2012) but are not at a particularly high level or comprehension. This again emphasises the lack of knowledge since the whole building does not tell the story. It is the individual common intensity of the faculty or academic area that holds the key to useful analysis and identification of areas for application, by comparison, of such benchmarks.

The report confirms (University of Sydney 2008, p. 61, b) that:

> Target data is calculated using our consultant’s IBER software, which compares data against other contemporary buildings of similar nature; target levels are constructed on a services by service basis as applicable to each analysed building and its activity level for that service; however there are unique features in the university buildings which are not considered by this method.

The questions raised by the above include:

- what are the ‘similar contemporary’ buildings that have been used for comparison?
- what is the methodology of the proprietary IBER software, and how it manipulates the data provided?
- while the energy saving methods applied to the services are well known, the undetermined issue for campus management is where and to what extent to apply such measures before appointing experts to individually evaluate each building and each service.

In conclusion, the *Energy Savings Action Plan* is a source of useful base information only, but it is not useful for ready identification of areas for improved energy reduction, or in predicting building energy consumption.

3.4.2 Utilities monitoring

This high level review report on utilities monitoring by Collins (2011), commissioned by Campus Infrastructure Services at the University of Sydney, reviews existing utilities information monitoring and comments on future strategies. It provides a brief overview of utility metering in the G08 universities.

Currently in 2015 the University of Sydney’s University Economic Model issues charges to faculties, departments and units based on costs and use for infrastructure and centrally provided services. The 2015 model has categories for type of services and for type of room (or area use) to appropriately proportion the activity charges. For example, for electrical supply and consumption, a faculty is charged on the basis of pool (or bulk) cost ($) at a unit rate ($), multiplied by the weighted usable floor area multiplied by two correction factors:

- category weight, such as laboratories (wet) weight of 1.3, laboratories (dry) weight of 1.1, offices weight of 1.0, teaching space weight of 0.9, workshops weight of 0.8, other
- building weighted all costs recovered: 1.00.

The category weightings have been allocated by the Sydney University UEM staff (to the G08 room categories) to allow predictions and allocation of energy costs. These weightings have been estimated by UEM from their internal modelling.

A typical laboratory (dry) would have an electricity charge based on $ (rate) x 1.1 x 1.0. What is relevant to this research is that the model recognises functional areas, which they reference as categories, having differing rates of energy use (or energy intensity). Additionally, the model system has differing room codes from the G08 space management data dictionary system (TEFMA 2015, Kuzcek 2014) more tuned to their perception of costs recovered. The topic of use of the LLO tool to improve accuracy of utility cost recovery benchmarks or adjustments is significant, as discussed in Chapter 6.

3.5 Summary and conclusion

This review highlights the gap in the knowledge specifically relating to energy use and management of tertiary education buildings.

In summary, the issues repeatedly raised by reviewers and users of the existing UK and US building energy benchmark schemes, provide, at best, an energy consumption benchmark for some whole of building in a campus, against a national database from which it is difficult to extract data to ensure a valid building and end use comparison for the subject building. Some of the published energy benchmarks, if applied to single use whole of building, assuming similar hours of operation and other operational and energy density and facade data, may provide a comparable example for good, typical and poor energy efficiency comparisons. But the more typical mixed use tertiary education buildings, with spaces such as offices, libraries, laboratories, amenities and circulation spaces, need to be disaggregated for valid comparison to functional area benchmarks. It must be noted that even buildings regarded as a single use, such as a research or lecture facility, in fact have multiple functional areas.
For example, building F19, Eastern Avenue auditorium, a modern specialised lecture room facility of 3046 GFA m² has less than 1200 m² actual lecture space, the remainder being circulation, office, cafe and other minor spaces.

The key to addressing the gap in the knowledge is first, to recognise the problem, as expounded by critics and users of the existing energy benchmarks for prediction and comparison of energy consumption. There is clearly a problem, masked by the current mass of aggregated data. What may pass as useful for common office buildings is problematic in mixed use, highly diversified in energy intensity, operation and facade, typical tertiary education buildings. A prime example is the University of Sydney University Economic Model for distributing central utility charges to faculties and departments based on a system of categories similar to functional areas (such as laboratory, office) with weightings applied to floor area, in attempt to more accurately reflect local energy use. Following on is the realisation that for existing mixed use campus buildings, disaggregation of energy consumption data is essential.

The next chapter presents the research methodology to address the gap in knowledge through development of the LLO tool.

4 Research methodology

4.1 Introduction

The aim of this research project is to produce a better tool for benchmarking energy use in tertiary education facilities. The methodology involved the development of a standardised method for collecting data, but iteratively refining the process by 'continuous improvement' by testing results from disaggregated functional areas against what aggregated whole of building measured data is available. The data was used to develop the LLO tool.

4.2 Key definitions: energy benchmarks and functional areas

Two key parameters of this research, energy consumption benchmarking and functional areas, are discussed. Benchmarking, benchmarks and energy use intensity are defined by Schofield (2014, section 1) as:

> Building energy benchmarking is a process in which the energy used by a particular building is compared with the energy used by other, similar buildings. Historically, benchmarking provides a simple method for a building portfolio manager to identify the poorly-performing buildings which are most likely to benefit from energy-efficiency upgrades. More recently energy benchmarking scores have been cited for building portfolios as evidence for energy savings (EPA 2012, USGBC 2012).

Benchmarking

Hyde et al. (2007) note the useful definition of benchmarking as "benchmarking is the continuous search for and adaptation of significantly better practices that leads to superior performance". This thesis research uses functional benchmarking. Hyde et al. (2007) note "the aim of this type of benchmarking is to investigate the performance of key processes, functions and activities in the building and benchmark them against the buildings that have similar core functions".

The critical issue for achieving a useful outcome is to ensure that the process characteristics (or research variables) being compared or benchmarked, are comparable, and clearly defined. This research is focused on energy consumption in buildings, related to a defined building area, over the period of a year, so the benchmarks are expressed in kilowatt hours per square metre per annum (kWh/m^2 pa).

Electrical consumption

The process being benchmarked in this research is electrical energy consumption in buildings. The definition of electrical energy consumption is clean and unambiguous. The electrical engineering and power supply industry uses kilowatt hour (kWh) as recorded by utility meters and recognised meters, measuring power distribution into and through the building or a designated area in the building.

The utility metered consumption data as measured will vary with the hours of operation of the building, reflecting the usage of electrical equipment, which is a surrogate for actual hours of operation. Accordingly, kWh/m^2/pa consumption, and its variation year to year, does account for variations in operating hours (refer "Functional Area Benchmarking" p. 45.

However, the majority of existing campus buildings may have whole of building metering, but are unlikely to have area or room sub metering, due to retrofit costs and lack of perceived benefit by campus building administrations (Collins 2011).

For typical stand alone office buildings, electricity is about 90% of total energy consumption estimated for 1999-2020, with tenancies being 100% electrical and the base building 83% electrical (*Baseline Energy*, Department of Climate Change and Energy Efficiency 2012). The report states for universities, the fuel mix in 2009 was about 71% electricity and 28% natural gas, expected to remain steady up to 2020.

In this research using the University of Sydney as a case study, benchmarking focuses on electrical energy, omitting gas, for several reasons (University of Sydney 2008, p. 31):

- local whole of building gas metering is not generally available
- applying energy efficiency measures to gas appliances (principally cooking) is problematical
- gas supply to campus represents approximately less than 18% of the electrical energy supply.

Functional area (academic spaces or 'activity areas') and energy consumption or energy density

Current consumption and future energy management is related to common functional areas, with the diverse buildings. The *Energy Savings Action Plan* (University of Sydney 2008) identifies the actual consumption of energy in typical tertiary buildings being principally due to:

- artificial lighting
- air conditioning, heating, ventilation
- office equipment, workshop equipment
- laboratory equipment and ventilation
- computer laboratories and equipment
- elevators
- cooking equipment
- Inappropriate and wasteful use, hours of operation of all of the above.

The proportion of each of the above and the significance to the total building consumption is determined by the:

- area – each of the functional area (academic activity or room spaces)
- occupancy intensity and hours of operation of the respective spaces per annum
- installed energy intensity of equipment and services.

The LLO tool developed and presented in this chapter addresses functional areas.

Functional benchmarking

The independent variables being measured or calculated to determine functional benchmarks and electrical energy consumption as recorded on the LLO spreadsheet A–P (Figure 10) are:

- hours of operation (by occupant information – see operating load factor)
- gross floor area (from plans or survey)
- input power of equipment (by survey) as corrected (see equipment load factor)

- basic facade and location (see fabric efficiency factor) (by survey) shown in the simulation study not to be significant - below about 7% of a typical functional area annual energy consumption
- controls for lighting and air conditioning/ventilation
- functional area type use (category 1-10)
- air conditioned or not (by survey).

Other variables not accounted for in the preliminary benchmark are:

- climate (normalised by 12 month calculation period) specific for Sydney CBD location. Other locations will require correction. It is intended to use Building Code of Australia climate zones 1-8, with correction factors referenced from the Building Code of Australia.
- building facade variations, other than fabric efficiency factor
- type and mass of building construction and facade to area ratio.

Additionally, from the DESC 9111, 24 building audit results, a distinction between wet and dry lab annual energy consumption was found not to be significant. Items (2) Hours of Operation, (3) Occupancy and (4) Installed Equipment (fig. 10 LLO Tool , p. 48) are the researched significant criteria from this study. Labs for the 21st Century (2015) does allow for this type of lab as a key normalising parameter with "lab type" and "lab use" able to be selected for bench marking.

4.3 Selection of research method for determining functional benchmarks

Functional benchmarks for energy consumption can be determined by energy auditing, sub metering or prediction modelling. Due to the availability of resources (or lack of) room by room energy auditing was chosen to carry out this research, to provide the most comprehensive understanding of the whole buildings while in use, leading to practical identification of the functional areas.

These researched benchmarks summarised in the LLO prediction tool (Figure 10) are intended to be used by building and faculty staff and campus management staff to enable:

- valid comparison between functional areas using normalised energy density benchmarks for comparison of high, typical and low consumptions (kWh/m² pa gross floor area)
- build up of these common functional areas between differing tertiary buildings to establish a method of comparing the generally available whole of building utility metered consumption data for these buildings, with correlations by functional area proportions, to establish meaningful and valid, high, typical, low energy consumptions
- prediction of functional area, and from a build up of the whole of building consumption a prediction of existing non metered buildings or future proposed buildings energy consumption. The difference between expected and realised energy performance has come to be known as the ‘performance gap’.
- identifying by comparison of best and worst practice, what works, what does not, what are significant causes of waste (unnecessary afters hours operations) across the energy consumption spectrum, within these buildings
- provision of data to assist to identify energy efficiency measures for functional areas.

As identified in the previous chapter, this data, necessary to facilitate effective energy management strategies, is currently not available for functional areas.

While there is considerable experience available in the application of energy efficiency measures to energy consuming equipment, such as lights, HVAC, office equipment, and to whole of buildings with uniform functional areas, including management, technology and equipment such as office buildings, the cost efficient prioritised application of such measures to tertiary education functional areas or whole of buildings is hampered due to lack of functional area normalised energy benchmarking.

4.4 Functional area energy benchmark prediction LLO tool development and validation

The derivation and development of the LLO tool, as shown in Figure 10 below, is described in this section. Figure 10 shows revision 6, reflecting the continuous improvement of the LLO tool.

ENERGY CONSUMPTION LLO BENCHMARKING RATING TOOL FOR CAMPUS BUILDINGS (rev 6)
(for use when room x room audit or sub metering data not available)

USER GUIDE - FOR EACH FUNCTIONAL AREA;

1. Using table 1, fill in information for your building(s) • metered electrical consumption • functional area (G08 room codes) sqm. GFA • whole of building GFA	**2.** Complete table 1, to produce a 'total score' to **rate** each functional area

TABLE 1: Guide for selection of low/med/high energy consumption benchmark estimates for functional areas

BUILDING ID	FUNCTIONAL AREA DESCRIPTION	FUNCTIONAL AREA/ ITEM, G08 CODE	GFA SQ.M	SUB METERED UTILITY kWh / annum or room audit data	GEOGRAPHIC LOCATION (BCA CLIMATE ZONE)	

			NOMINAL SCORE	ACTUAL SCORE
1	NCC/BCA CLIMATE ZONE (5)	Sydney Metro	1.0	
2	HOURS OF OPERATION P.A.	Approx. 2800 or;	1.05	
		Approx. 2000 or;	1.00	
		Approx. 1040	0.54	
3	OCCUPANCY standard	1 person per 10 m² or;	1.00	
	OCCUPANCY high density	50% and above (typical space - lecture theatre) or;	1.25	
		50% and below (typical space - lecture theatre)	1.07	
4	INSTALLED EQUIPMENT	Heavy (40 + watts per sqm +) or;	2.34	
		medium (25 to 39 watts per sqm) or;	1.00	
		Low (10 to 24 watts per sqm)	0.57	
5	LIGHTING (general space - not including local task on desks)	Older T12 (iron core ballasts) or incandescent or;	1.28	
		Modern fluoro (T8, T5 ballasts) or LED	1.00	
6	AIR CONDITIONING/ELECTRIC HEATING	Fully air conditioned/electric heated (central or local) or;	1.00	
		Partially air conditioned/elec. heat (less than 50%) or;	0.91	
		No air conditioning	0.84	
7	CONTROLS (for lights)	Auto timers, movement sensors, BMS for room or functional area or;	0.92	
		Local manual switch for room or functional area	1.00	
8	CONTROLS (for air conditioning/elec heating)	Auto timers, movement sensors, BMS for room or functional area or;	0.92	
		Local manual switch for room or functional area (digital electronic)	1.00	
		TOTAL SCORE (1-8)	TOTAL SCORE	
		ABOVE 9.0	HIGH	
		8.0 TO 9.0	MEDIUM	
		BELOW 7.0	LOW	

3. Using table 2, identify the **energy consumption benchmark** for your functional room or area by applying the **LOW, MED or HIGH** score identified by the **'ACTUAL TOTAL SCORE'** in table 1.

TABLE 2 : Provisional LLO energy consumption rating tool benchmark estimates

LLO ITEM NO.	G08 ROOM CODE	LLO USAGE, SPACE, AREA DESCRIPTION	BENCHMARK kWh/m²/A (GFA)		
			low	medium	high
1	1	Office (with associated areas similar to Nabers office energy requirements	60	130	200
2	5	Library	100	160	220
3	3	Computer Lab (over 15 desk tops)	180	280	380
4	2	Lecture room (over 15 seats)	100	200	300
5	6	Commercial (staffed) kitchen/cafe	350	650	950
6	4	Workshop	100	330	560
7	3	Teaching labs (under grad)	70	120	170
8	3	Research labs (post grad)	50	150	250
9	5	IT server rooms (not included in 1 above)	200	1500	5000
10	6,7	other	40	140	240

4. Compute **annual energy consumption** for the functional area or room ;
Multiply **(GFA) m²** x **benchmark (kWh/m²/A)** (table 2, low, med, high) = estimated electrical energy consumption

(Area) ____________x (benchmark) ______________ = ___________ kWh/A = total functional area total

5. Total all functional areas (GFA) for the building and benchmarked electrical energy consumption for a **comparison check** against total GFA and total utility meter data energy consumption for the whole building.

Figure 10 The LLO tool (also see Appendix 1)

This tool is designed to be completed by building or faculty managers with no required mechanical or electrical services expertise, to allow ready calculation of a functional area energy consumption benchmark, from a visual non expert inspection and a knowledge of the operation and use of the building. It is intended to be quicker and easier to use than any comprehensive building modelling program. It is intended not to require advice from mechanical, electrical or services engineers. The tool has been developed to allow functional area characteristics to be 'scored' or selected to enable a functional area energy benchmark to be determined.

The literature research references several benchmarking tools, including CIBSE's *Guide F* (2012) TM22 (CIBSE 2012), US Energy Star, CIBSE's Carbonbuzz, ASHRAE Building Energy Quotient and Green Star Education VI (Green Building Council of Australia 2015). All have merits but are not designed to provide ready determination of a campus building functional area energy benchmark.

LLO benchmarks

The researched benchmarks, indicated in Table 8 (kWh/m² pa) and the LLO tool, Figure 5, are from the building room by room audits, collated and corrected from spreadsheets A–P, after application of the efficiency load, operational load and fabric efficiency factors and checked against aggregated +/- 10% Campus Infrastructure Services supplied electrical consumption. The benchmarks are presented as a range of low, medium and high to reflect the spread of accuracy inherent in data collection for energy benchmarks. This reflects similar presentation to CIBSE TM54, chapter 7 (CIBSE 2013).

LLO scores

The modelled scores are essentially a sensitivity analysis from a Design Building simulation study completed by Team Catalyst under instructions from and supervision by the researcher (Appendix 2), performed on a modelled typical 400 m² functional area with nominated features equivalent to teaching lab LLO room code 7 or 8, or office room code 1, or computer lab room code 3. The purpose of this study is to apply a rational criteria validated by specific modelling to allow the LLO tool user to select from the range of benchmarks provided.

LLO tool development from the simulation study

Review of the 21 simulation study Design Builder/Energy Plus program runs, for assumptions and conditions is shown in Table 6.

For the design of the LLO tool, from research of existing tools (sect.. 2.4.1, 2.4.2 and 2.4.3) and the author's experience with 24 campus buildings, and current industry information (sect. 4.8.2 Independent Variables selected), to achieve a practical balance between rigor, accuracy and usability, the significant independent variables to allow a simply calculated benchmark for functional area energy consumption had to be selected.

Table 6 (p. 50) provides a summary of the independent variables for which Design Builder modelling (appendices 2,3 & 4) indicates greater than a 7% change in the kWh/sqm/A and calculated LLO score. Table 7 (p. 52) is a summary of the full Design Builder simulation study (appendix 3) covering the full range of selected independent variables (sect. 4.8.2) from which table 6 independent variables have been selected.

Table 6 Significant independent variables which indicate greater than 7% change from the (1a) base run

Run number	(Variance to 1a score = 0.90	Independent variable	LLO score adjusted 10% for run 1a baseline match
Run 8	1.14 = +27%	High occupancy density (300 persons)	1.14 to 1.25
Run 9	0.98 = +9%	High occupancy density (100 persons)	0.98 to 1.07
Run 10	1.17 = +30%	High lighting intensity 20w	1.17 to 1.28
Run 11	0.76 = - 15%	No air conditioning	0.76 to 0.84
Run 12	0.83 = - 7%	Mixed mode air conditioning	0.83 to 0.91
Run 13	0.84 = - 7%	BMS lighting control	0.84 to 0.92
Run 15	2.17 = + 140%	High internal plug in load	2.17 to 2.34
Run 16	0.52 = - 42%	Low internal plug in load	0.52 to 0.57
Run 17	0.49 = - 45%	Low hours of operation (1040 hours)	0.49 to 0.54
Run 18	0.96 = + 7%	High hours of operation (2800 hours)	0.96 to 1.05
Run 1a	0.9 = + 10%	Base line without roof solar load	0.90 to 1.00

The modelling indicates as shown in Table 6 above the significant independent variables (those selected having 7% or above change to the run 1a baseline) which are:

- installed equipment energy intensity
- type of lighting and air conditioning
- controls – lighting and air conditioning, manual or automatic (BMS)
- operational – hours of operation and occupancy
- occupancy intensity.

Facade features for annual energy consumption calculation

For this selected typical functional area, the north facing facade comprised 50% glazing with assumed air conditioned space above ceiling and below floor (adiabatic conditions adjacent, that is, zero temperature difference). The facade variations, % of glazing up to 75%, down to 25%, degree of external shade overhang (to 50%) in runs 2, 3 and 4 all had less than 3% difference to the run 1a baseline and so were not included in the LLO tool.

Controls

Due to the selected Building Code of Australia JV3 school schedule 9B showing the weekday lighting operating much more extended hours than the heating, ventilation and air conditioning, which is unrealistic for a campus, the control score for heating, ventilation and air conditioning is adopted as for lighting.

Discussion on climatic variations

The LLO tool (revision 6, Figure 5) indicates a requirement to identify geographic location by choice of National Construction Code/Building Code of Australia climate zone and nominates (no. 1) Sydney metropolitan area, climate zone 5 with a score of 1.0. The variance in annual energy use due to exterior climate variations are detailed in many references, discussed later in this chapter. The exterior factors (independent variables) relating to exterior temperatures, relative humidity and solar radiation, affect the facade heat transfer and ventilation thermal load.

National Construction Code/Building Code of Australia Figure A1.1 shows climate zones for thermal design (Australian Buildings Codes Board 2015). Section J Energy Efficiency of the National Construction Code/Building Code of Australia shows a multitude of climate zone selection criteria for the differing elements of climate contributing to energy efficiency and which area regulated by the National Construction Code/Building Code of Australia volume 1 (2015), including facade and services. Generally the climate zone factors affecting the LLO tool and its use can be indicated by reference to the following National Construction Code/Building Code of Australia Section J tables:

- J1.3a – roof and ceiling insulation values
- J2.4 – glazing energy index allowances
- J1.5a – external wall insulation values
- J1.5b – envelope wall - that is other than external wall minimum insulation values.

These tables have been applied to the LLO tool, which does not include (as indicated in the simulation study) fabric variables, as:

- climate zones 1, 2, 3, 4, 5 and 6 = 1.0 estimated LLO score
- climate zone 7 = 1.5 estimated LLO score (subject to further study)
- climate zone 8 = 2.5 estimated LLO score (subject to further study).

The Design Builder simulation study (see Table 7 below and Appendices 2, 3 and 4) related to the independent variables shown in the LLO tool (revision 6) rows. Their selection is discussed later in the chapter. The simulation study assumptions and criteria are detailed in Appendices 2 and 4. The selected time schedules for the model are from Building Code of Australia Section J, Spec JV3, class 9B school schedule.

The simulation study demonstrated issues relating to the use of modelling, for even a small study of 20 runs of a rectangular shape with one exterior facade. The issues are that within the Design Builder algorithm and the time schedule used (in this case 9B classroom BCA - JV3) there are combined adjustments affecting the use and intensity of lighting and HVAC system together with variations in occupancy in addition to the ambient external conditions and provided by Bureau of Meteorology weather data file.

For example, the 9B schedule automatically adjusts the occupancy and lighting (see Appendix 2) which contracts with the actual situation of outside air for the ventilation component of air conditioning which for most air conditioning systems in campus buildings (all 14 buildings in the *Energy Savings Action Plan* and 24 buildings audited in DESC9111) does not vary with occupancy or hours of use.

These issue illustrate a problem with modelling. That is, to represent a subject building or functional area accurately is difficult, even with all the options for assumptions and inputs, and any outcome has to be viewed with experienced and professional judgement, as confirmed by the literature reviews . (Montgomery , CIBSE TM 54, Hyde et al)

Table 7 Design Builder simulation study (see Appendix 3 and 4)

SIMULATION STUDY LLO RATING TOOL REV 1 03/11/15

% GLASS	ARCH FACADE	GLASS TYPE 6mm shgc 0.8	EXT GLASS SHADE	EXT WALL TYPE	PARTITION TYPE	CEILING TYPE	ROOF TYPE	FLOOR TYPE	OA L/SEC	OCCUP DENS	PLUG IN LOAD	LIGHTS	AC TYPE	CONTROLS LTS	CONTROL S A/C	HOURS OF OPERATION	OCCUPANCY	MODELLED ANNUAL KWH/SQM	LLO SCORE
1. baseline	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	none	u=1.7 uninsulated	u=3.4	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	103.32	1.00
1a	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	92.61	0.90
2	75% = 40.5sqm	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	95.67	0.93
3	25% = 13.5 sqm	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	90.39	0.87
4	50% 27 SQM	u=6.0	50% ext	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	90.7	0.88
6	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	u=2.5	none	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	92.08	0.89
7	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	none	u=0.5 insulated	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	92.88	0.90
8	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	at 1:1 75% = 300	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	118.3	1.14
9	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	at 1:1 25% = 100	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	100.98	0.98
10	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	20w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	120.48	1.17
11	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	no AC	local manual	local manual	2000	50%=20	78.15	0.76
12	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	mixed mode	local manual	local manual	2000	50%=20	85.8	0.83
13	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	CBUS BMS	local manual	2000	50%=20	86.5	0.84
14	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	CBUS BMS	2000	50%=20	92.77	0.90
15	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	75w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	224.56	2.17
16	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	10w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	50%=20	53.87	0.52
17	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	1040	50%=20	50.87	0.49
18	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2800	50%=20	98.74	0.96
19	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	25%=10	91.94	0.89
20	50% 27 SQM	u=6.0	none	u=1.6	u=1.9	adiabatic	N/A	adiabatic	10 p.p.	1:10=40	25 w/sqm	10w/sqm	1 zone VRV split	local manual	local manual	2000	75%=30	93.63	0.91
STUDY	BASE LINE SCORES 1.0																		
	UNES2 TO 20 - SCORES ? RATIO OF KWH/SQM TO BASELINE						FOR RUNS 2 - 20 - KEEP "BASELINE" VALUE EXCEPT AS SHOWN IN RED												

Table 7 summarises the 20 modelling runs serving as a sensitivity analysis for the independent variables originally selected for the LLO tool, reduced to those variables showing a score with 7% or greater deviation from baseline run 1a (see Table 6).

4.5 Data requirements

To establish energy consumption for tertiary building functional areas, it is necessary to identify and measure area (gross floor area in square metres) and energy consumption (kilowatt hours per square metre per annum). Methodologies for collecting the necessary data for existing buildings for energy audits are well documented in *Guide F Energy Efficiency in Buildings* (CIBSE 2012), ASHRAE *Standard 100-2015 Energy Efficiency in Existing Buildings* (2015) and Australian Standard AS3598.1 (2014) Energy Audits and include:

- local sub metering
- prediction by modelling
- survey and energy audit.

Data available from Campus Infrastructure Services at the University of Sydney for the selected buildings includes:

- room by room floor plans with schedule of areas and G08 room and area space utilisation with gross floor area, usable floor area and building area
- whole of building energy utility data for electricity (kWh pa), with limited data on gas (megajoules pa).

Additionally available from building energy utility data is normalised per area and per population (effective full time student unit). Of the area metrics available, gross floor area is selected as it best represents the area provided with energy consuming equipment and best corresponds to the common commercially used gross floor area as defined by the Property Council of Australia in their document Benchmarks of Operating Costs (undated).

The literature search indicates as in Table 9, there is overseas material collated from various sources to provide guide energy consumption data for specific use areas within campus buildings. In the case of HEEPI (ref. appendix 6B) and CIBSE Guide F from the UK and Lab21 from the USA, the data has limited applications to Australian functional areas due to:

- differing methods for measuring areas and other independent variables
- local climatic variations
- differing use of gas and electricity as energy sources
- unspecified operational and system end use issues
- differing output methods, in some cases by comparison with a national database

Chapter 20 in CIBSE Guide F (2012) (table 20-1) (ref. appendix 6A) which contains all the UK energy component benchmarks at the time of publishing (March 2012) notes that "These benchmarks date back to the guide and some of the primary sources are no longer available. However, they represent the best information that is currently available". All of the above means these benchmarks do provide generic guidance, but cannot be used to populate the LLO tool table.

The University of Sydney energy audit in DESC9111 2009 and 2010 predates CIBSE Guide F (2012) publication and includes the essential correction and operational factors which need to be applied to equipment name plate data to achieve useful results.

4.5.1 Local sub metering

The most accurate method of establishing actual energy consumption for room, space, or functional area, is to install quality metering equipment (NABERS 2010). For the new or extensively renovated existing buildings, this can be practical and cost effective when the ongoing benefits of energy consumption management and control can be quantified and related to the appropriate return on investment. However, for existing buildings, with appropriate quality sub meters (electrical), the potential cost of the necessary rewiring to allow electrical services and equipment rooms and areas to be grouped as functional areas is generally too expensive. Beggs (2009, p. 161) notes that "to achieve such level of data will invariably require sub metering and may incur significant cost to the institution".

4.5.2 Prediction by modelling

There are many building energy prediction software model packages available including Design Builder/Energy Plus, ACADS-BSG Camel/Beaver, Thermal Analysis Simulation Software (TAS), Institute of Applied Simulation (IAS) and others which have been shown to comply with ASHRAE 140 Best Test, an internationally recognised protocol for such models.

The software program Design Builder is available in the Faculty of Architecture, Planning and Design at the University of Sydney. The reported problem using modelling is accuracy of outcome (CIBSE 2013, Department of Climate Change and Energy Efficiency 2012) due to not collating operational experience and practical current layout details including:

- change of internal use
- refurbishments and renovations
- change in equipment and HVAC systems.

The issue is the time and cost for multiple buildings with multiple internal areas, and accuracy of results. CIBSE (2013) notes:

> There has been a growing awareness for some time that many "low energy buildings" use more energy than the designers thought they would. As energy costs have risen, this awareness has started to spread to building owners, who hear much about low energy buildings and subscribe to programmes that rate the design of the building, only to find their 'low energy design' turns out to have a typical energy bill. The performance of low energy designs is often little better, and sometimes worse, than that of an older building they have replaced, or supplemented.
>
> This phenomenon is not restricted to the UK, but has been observed as far afield as the US and Australia. There is a mismatch between the expectations around the performance of new buildings and the reality of the utility bills. This difference between expected and realised energy performance has come to be known as the 'performance gap'.
>
> There are two main reasons for this performance gap. The first is that the method of calculating energy use for the purposes of compliance does not take into account all the energy use in a building. In particular, it does not address energy used by lifts and escalators, for catering facilities, or for server rooms. This energy use can be substantial; in one case study, the National Trust HQ at Swindon, it was found that 60% of the energy use, that for the server room and the catering, was used in just 3% of the floor area, and more than doubled the operational energy use over the design estimates.
>
> The second reason for the performance gap is related to site practice. To deliver a building that uses as much energy as expected requires that the design is built as intended, the engineering systems are commissioned effectively and the operators and occupiers of the building

> understand how to operate and maintain the building so that it delivers the expected performance.

Hyde et al. (2007, p. 200) note:

> Benchmarking in the context of BEA tools is still a weak science. For example benchmarks created through computer simulation are yet to be effectively reconciled with operational performance, particularly in the energy area.

To avoid the 'garbage in' and 'garbage out' issue, any modelling protocol requires qualification of inputs and variables which are most accurately gained from building survey and staff interviews, by trained personnel, so it is strongly recommended to proceed to building energy audit which includes at least a walk through, but for relatively accurate results, room by room survey by trained personnel.

For energy modelling, the modelling parameters and input guidelines require comprehensive and detailed technical input regarding weather data, facade, architecture, services, controls and operational data and use of modelling software that complies with 'best test'/ASHRAE 140-2001 or equivalent.

4.5.3 Energy audit – room by room survey

Due to the limitations of sub metering and modelling and because of the resources available for this research, the selected method is energy audit by room by room survey for data collection. This audit is equivalent to a Level 3 AS/NZS 3598: 2000 audit and survey and in accordance with Thumann et al.'s *Handbook of Energy Audits* (Chapter 17 World Class Best Energy Assessments*)* (2009); CIBSE (2012) and notably, the critical audit review by CIBSE in TM54 (2013).

Knapp (2006), Thumann et al. (2009) and Spielvogel (2015) all advise no other method provides a such detailed picture of the current use and installed or applied energy intensity when combined with staff structured interviews and trained team of auditors. The training program used in the graduate subject DESC9111 is presented in Appendix 5.

The buildings selected for audit were on the basis that Campus Infrastructure Services could provide electrical energy annual consumption metered data, for at least the whole of building. No data was available for functional areas or rooms.

The role of the building manager, meaning administration or academic staff, or both, having a detailed working knowledge of the building, its operations and equipment, is essential in the data gathering process. Initially when the audit process commenced in 2009, attempts were made to have a staff survey and questionnaire to gather information and operational experiences from a range of occupants and staff using the building, including comments from these users on their observations on energy efficiency or waste. However, this proved not to be successful. This was due to a general lack of interest by building users, occupants and staff, in the energy audit process, so when meetings were arranged, attendance was poor and answers to specific queries were not comprehensive. Aside from a few anecdotal queries about lack of facilities after hours, security issues and complaints about lack of comfort due to poorly performing heating and cooling systems, individual staff did not appear to have a complete understanding of how the building operated.

As a contrast, the program received quality engagement from senior campus administration staff, responsible for a particular building, and in some cases, senior academic staff also. These senior staff were contacted individually by the author, face to face or phone, to explain the program and outcomes. Engagement was the key.

4.6 Data collection

4.6.1 Training for and completing the building audit and survey

The activity consists of several elements including:

- training the graduate student audit teams. This training program was trialled in 2009 and 2010, in university staff and volunteer teams from industry (Investa, Stocklands). These industry teams completed building audits. Their feedback was used to upgrade the current training program (Obrart 2014 in Appendix 5).
- brief overview of the building with Campus Infrastructure Services (technical) staff and introductory meeting with the building manager to expedite the process and solicit operational information
- audit day, when a trained team, with supervision from the subject co-ordinator (Alan Obrart), complete the room by room survey, using Campus Infrastructure Services provided floor plans, recording energy consuming equipment on the LLO spreadsheet
- feedback meeting between the audit teams, building and Campus Infrastructure Services staff, to present initial findings for critical comment
- assumptions inherent in the audit data collection include: building and services maintenance is current and operating systems area commissioned, what appears to be redundant and superseded equipment is in fact not used, and that energy consumption equipment with automatic controls, particularly lighting and environmental systems, have these controls operating correctly, so that the LLO recorded operational assumptions are consistent with the actual system and equipment operations.

4.6.2 Data recording and results spreadsheet

These spreadsheets capture the survey data recorded on the audit day.

A most important function of the audit day question and answer session (1 hour meeting) with the building manager was to find out the current actual operational data 'hours of use' and occupancy factors of the functional areas. Note CIBSE TM54 (2013) and *Baseline Energy* (Department of Climate Change and Energy Efficiency 2012) confirm lack of accurate operational data is a major impediment to predicting energy consumption accurately.

The audit team complete the spreadsheet (rows A-P/LLO) and make fabric efficiency factor, operational load factor and equipment load factor adjustments to the recorded data, then sum the room by room estimates to compare with the actual annual (electrical) consumption provided by Campus Infrastructure Services for the complete building.

4.6.3 Difficulties identified with room by room survey and data collection

The difficulties experienced with energy audit room by room survey and data collection are considerable and have the potential to affect the accuracy of outcomes, even with the comprehensive cooperation from high level skilled staff from Campus Infrastructure Services. There are three issues of concern.

1. For existing buildings, building plans with room by room areas and descriptions may not be up to date. They do not describe the use.
2. Significant cooling, heating and ventilation in sections of some buildings serve multiple rooms and functional areas which require their energy consumption to be allocated across the areas they serve. This is because during a room by room survey and audit, the extent of remote equipment serving a particular room by pipes or ducts is not apparent. The process has to be firstly to survey the remote system to ascertain the total energy consumption, then allocate an estimated proportion to a particular area in proportion to the area being served, guided by (if available), the appropriate functional area benchmark.
3. A further significant difficult in the audit and survey of building systems is ascertaining the status of the operating controls. Essential to an accurate survey is to have the assistance of a technician with an intimate understanding of the existing controls systems and their current settings. Drawings and documentation are helpful, but generally not adequate as they are unlikely to provide the current status of controls operations for at least, the lighting and environmental control systems, the major consumers of energy. The controls systems operating criteria are critical to the energy consumption of the building audits functional areas, as they should regulate the times of operation and (depending on the systems or plant characteristics) the capacity of the systems being delivered and the related energy consumption. It is not generally within the skill set of even a well trained audit team to have the time or expertise to thoroughly check an automatic building management of services, to ensure compliance with the current operational intent. For example, are the actual settings of any automatic timers consistent with the actual operational requirements? Do the lighting and environmental control systems switch on and off, in accordance with use of any room or space? Aside from refrigeration or process equipment, is there any equipment running 24/7 wasting energy when rooms are not in use, or at full capacity when rooms are only partially occupied?

A	B	C	D	E	
RM NO. & ID	LOCATION & GFA (SQM)	USE CATEGORY	FABRIC EFFICIENCY	EQUIPMENT	
		(1) TO (10)	FACTOR (FEF)	ITEMS	
example	example	example	example	example	
room 536	L5 east GFA - 150 SQM	Cat 3	x 0.9	copier	each or common group;
computer lab		AC	x 1.2	twin fluoro	Condition : poor, satisfactory
		room/central	if N/A use 1.0	room split AC	redundant
				bench saw	control
		Non AC		refrigerator	local (room) manual/auto
					or
					central (corridor or plant
					room) manual/auto

F	G	H	I	J	K
QUANTITY	NAME PLATE	ELF	TOTAL EST. KW	EST. NORMA	EST. WEEKLY OP
	KW			WEEKLY OP I	AFTER HOURS
example	example	example	example	example	example
8 OFF	700 watts	x 0.7	(d) x (f) x (g) x (h)	1800 HOURS	8 HOURS
			equals KW	note; list if area vacant	

L	M	N
EST OP. HRS PE	OLF	TOTAL EST. HRS PER ANNUM
		P.A.
example	example %	example
use J & K plus sei	0.6 or 60%	use; (L) = HOURS
non semester, hc	proportion of	or
	(L) to 8760 hours	OLF (m) x 8760
		= hours
		This will produce
		the same result
		for N

O	P	COMMENTS
TOTAL ENERGY	% OF TOTAL ENERGY	
	CONSUMPTION %	
example		
(i) x (n) = KwH/ANNUM		
compare with utility bill - comment on difference		
÷ GFA to show kWh/annum/sqm		
show kWh/sqm/annum for EACH usage category (1) to (10)		
air condtioned		
non air conditioned		
to establish usage categoty benchmark		

Figure 11 LLO spreadsheet headings for data collection A to P room by room
Source: Obrart (2014).

4.6.4 Use of the LLO tool

The user applies this prediction tool, shown in Figure 10, as follows:

1. Select the functional area and location criteria.

2. Accumulate a 'score' for a selection from independent variables which influence energy consumption, relating to the functional area building and its operations. The scores are quantified by Design Builder modelling of these variables (Appendix 2).

3. Accumulate a 'score' for a selection from independent variables which influence energy Add the accumulated 'score' from Table 1 in Figure 10 to allow selection of a 'rating', low, medium or high range as quantified in Table 2 of step 3 for the appropriate functional area.

4. Compute the functional area benchmark by application of: area (gross floor area) x selected benchmark (kwh/m² pa).

5. Do a reality check. If the whole building is broken down into its multiple functional areas and each functional area is benchmarked using this LLO tool, then all of the functional areas and benchmarked consumption should be added to check against the building gross floor area and utility measured annual consumption, to be within +/- 10% of the Campus Infrastructure Services provided whole of building electrical consumption.

4.7 Accuracy of energy benchmarks

The literature review of *Baseline Energy* (Department of Climate Change and Energy Efficiency 2012), Liddiard et al. (2008) on TM54 (CIBSE 2013) and TM46 (CIBSE 2008), Ruyssevelt's (2014) review on CarbonBuzz and Schofield's (2014) review of Energy Star all indicate the extent that building energy data is based on large samples from survey results, not from trained audits of buildings. There is a comprehensive debate as to the statistical analysis of the result presentation by authors and reviewers. For instance, Department of Climate Change and Energy Efficiency in *Baseline Energy* (2012, p. 9) notes:

> Changes in the nature, composition, performance specifications of inputs, processes or outputs, in this context, changes in qualification factors or specifications, can significantly affect measured energy consumption, particularly over longer periods of time.

In terms of purpose of benchmarks and accuracy requirements, for commercial offices, provision of energy consumption whole of building benchmarks may be used for:

- energy (or sustainability) rating which will affect potential building commercial value by return on investment via rentals
- regulation compliance, such as UK display energy certificates and Australian commercial building energy certificates certification.

For these quantifiable outcomes, verifiable accuracy of energy benchmarks are expected. However, for university campus buildings, the expectations and use of energy benchmarks differ. Whole of campus, whole of building benchmarks are currently used by TEFMA and the individual administrations for broad energy efficiency comparisons, possibly separating general purpose from energy intensity buildings and to assist in future power supply infrastructure planning, and to assist with future power cost estimates.

The LLO tool functional area energy benchmarks also allow, principally as a guide to energy efficiency:

- valid comparisons between like functional areas in dissimilar buildings
- identification of energy waste and poor performance
- prediction of whole of building energy consumption by aggregation of functional areas.

But all of these uses do not require the same accuracy stringency as the commercial priorities of office buildings.

4.8 Accuracy of LLO benchmarks

The LLO prediction tool is the product of a sensitivity study applied to researched benchmarks. The researched benchmarks in Table 8 are a result of trained audit team survey recording in spreadsheet A-P, applying operational factors and achieving a resulting benchmark for functional areas which aggregate to a total +/- 10% of the utility (electrical) consumption of a building.

An important factor in achieving this accuracy is the attention to detail by the trained audit team (see Appendix 5) including covering the detail recommended in the critical study TM54, with technical assistance from building and Campus Infrastructure Services staff. Allocation of remote or central energy consuming equipment to appropriate rooms and functional areas, with attention to their control strategies, is essential.

The sensitivity study (Appendix 2 and 3) from Design Builder modelling of a typical academic functional area provides modelled comparative 'scores' for each of the independent variables in the LLO tool. Although there are well-documented problems with achieving accuracy with modelling, in this instance to the specific modelling applied, due to care and expertise in collecting operational data, the results should be satisfactory.

The office building databases are very extensive, allowing (after some discussion) valid statistical comparison to be made for a subject office building to the database, presented as a high, typical, low outcome. However, the much smaller tertiary education building databases do not lead themselves to uses such as prediction, and as functional areas are not fully identified in databases, the Design Builder specific modelling is preferred for development of the LLO tool.

The fundamental accuracy of data in Tables 4 and 8 has been tested by the reality check of comparing the DESC9111 audit results in Table 4 summed against the actual utility accounts for annual energy consumption. In addition related whole of building and to a limited extent functional area information from UK and US sources is reviewed taking into account the differing climatic environment and other factors.

4.8.1 Regression analysis

Regression analysis to determine the relationship between energy use and the drivers that influence it is conventionally done, as outlined in *Guide F* (CIBSE 2012), by developing a performance line equation $\gamma = mx + c$, with *Y* axis as energy consumption; and *X* axis, some independent variable.

Typically the independent variables are physical building attributes, area, facade, services and controls, and operational issues, hours of operation, occupancy and controls.

As the researched result sample in Table 4 and 6 is relatively small, 24 campus buildings and 80 functional areas across 10 types (note Green Star Education VI is based on 19 faculty returned questionnaires and CarbonBuzz on reports from between 13 to 40 campus buildings), more useful results are generated to provide 'the score' by targeted modelling, than by some correlation factor from a series of $\gamma = mx + c$ lines for each of the independent variables charted against energy consumption.

The benchmarks shown in the LLO tool ranged as high, medium and low are informed by the results from actual building audit LLO spreadsheets A–P.

4.8.2 LLO tool assumptions

The assumptions implicit in this accuracy discussion relate to the correct selection of 'independent' variables and the typical case selected for comparison, including physical building and operational considerations.

Independent variable criteria

The criteria in the LLO tool Figure 10, selected for sensitivity analysis of functional areas, and used as input to the Design Builder model are selected from the physical and operational variables that have a significant impact on energy consumption of a 'typical' functional area. This model is based on University of Sydney experience in the 24 buildings surveyed, both physical and operational data, single level 400 square metre room with single external facade.

Independent variables selected

Independent variables selected are those which substantially affect energy consumption and which are likely identifiable by building or academic staff (not expert in energy use assessment) who are required to fill in the LLO tool form (Figure 10).

1. NCC BCA climate zone
2. hours of operation
3. occupancy
4. installed equipment
5. lighting
6. air conditioning/electric heating
7. controls (lights)
8. controls (air conditioning and electric heating)

It is not within the scope of this work to analyse the thermal modelling techniques which industry uses to simplify the science of heat transfer into predictive tools for engineers to calculate (manually or by modelling) the energy consumption consequences of building services to assist occupant function and comfort such as ASHRAE Fundamentals 2013 (Chapter 18 Non Residential Cooling and Heating Load Calculations), CIBSE's Guide F (2012) (Chapter 2 Design Process) and Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in particular AIRAH DA9 (*Air*

Conditioning Load Estimation). This above literature, together with reviewed literature for existing energy predictions tools such as CarbonBuzz, building energy quotient, TM22 and the Design Builder Handbook, all provide a clear indication as to what needs to be included as an independent variable.

In practice (not within the scope of this study) there is no substitute for trained practitioner experience in carrying out manual calculations of building and thermal loads and use of approved models (such as Design Builder, or ACADS BSG Camel/Beaver) for which AIRAH DA9 is the manual forerunner.

Lee (2011, p. 331), comparing their relative energy use assessments of BREEAM and LEED only, notes:

> The minimum performance level specified in BREEAM for $C0_2$ emissions is an absolute level for all end users, while other schemes stipulate a minimum percent enhancement of performance relative to the baseline energy use.

Lee (2011, p. 332) also notes, regarding simulation tools, provided simulation programs are equivalent to the ASHRAE Standard 140 Standard Method of Test:

> ...the differences between simulation programmes caused by algorithmic differences, modelling limitations input differences etc, simulation tools specified by different schemes will not affect the simulation accuracy to the degree where the predictions are erroneous or have large uncertainties.

The significance of Lee comments is that the selection of a model, in this case Design Builder over other proved (ASHRAE 140 Best Test) models, is not significant.

Hence, selection of the LLO tool 'scored' independent variables is essentially based on observation of the buildings and operational information from building and academic staff, and 'selection' of the independent variables is by reference to the Design Builder simulation study (appendix 2,3 & 4).

4.8.3 Data correction factors

The aim of the audit is to predict annual electrical consumption that is the product of power (kW) x time (hours). TM54 (CIBSE 2013) confirms in detail earlier omissions of the energy auditing industry by not taking into account the differences:

> Wherever possible, the actual energy use of the equipment should be established, rather than the nameplate ratings... appropriate margins should be allowed to take into account of the difference between ideal performance and how the building is likely to operate.

Accordingly, equipment load, operational load and fabric efficiency correction factors are applied to the audit teams' room by room data to more accurately predict the actual energy consumption, by using the best observable and supplied information. As discussed earlier sections, the trained auditors record their room by room electrical equipment consuming data on the LLO data collection spreadsheet columns (see Figure 11).

Equipment load factor (ELF)

Column G records the equipment or appliance manufacturer's name plate rating, indicating (depending on the government regulations in the country of origin, or of use) 'normal' and 'peak' power consumption use watts (or kW), various current ratings and voltages. These ratings are designed for safe connection to the electrical power, so as not to exceed wire and switching safety ratings. The issue is what proportion of the ‘nominal/maximum’ power is actually used by the equipment in its various modes of operation (not peak, not minimum). See for example, Machine Z in Figure 12 below.

Example – Machine “Z”
1000w nameplate (with estimated, manufacturers rated, or measured normal input 800w, etc) or ELF of 80%=800w (or ELF of 800/1000=80%) , and standby 200w, (or ELF of 200/1000=20%) and may have staff estimated normal usage of 1,752 hours (that is OLF of 1752/8760=20%), plus standby of 876 hours (that is OLF of 876/8,760=10%)
The spreadsheet lines could be for this item of equipment “Machine Z”:
normal mode 1000w x ELF 80%, (or x 800w x) x OLF 20% (of 8,760 hours) (or 1,752 hours) = 1401 kWh pa
plus standby mode 200w x ELF 100% (or 200w) x OLF 10% (of 8,760 hours) (or 876 hours) = 175 kWh pa
Total for “Machine Z” 1,576 kWh pa – normal plus standby modes of operation - 1401 + 175 = 1,576 kWh pa.

On audit spreadsheets, DON’T OVER CORRECT by applying % to the “assumed” kW or hours figure. See columns M and N.

Figure 12 Example of application of correction factors to Machine Z
Source: Obrart (2014) slide 455.

This is a comprehensive example of the application of correction factors equipment load and operational load factors to the room by room survey and audit equipment data. This means the nominal equipment or machine rating is modified by an equipment load factor Column H, to determine as close as the operational information for this space will provide, a realistic consumption figure, total estimated electrical power and shown in column I (kW).

Fabric efficiency factor (FEF)

These are the author's experientially based correction factor, summarised from the review of many thermal calculation estimates as they affect significant inputs into a room thermal load and are suitable for application by room x room energy auditors.

Note that instructions to auditors indicate that if they have difficulty with the FEF correction, simply use the default as 1.0 when using the LLO spreadsheet.

Column D lists the fabric efficiency factor. This is available as a correction to the total kW (Column I). The fabric efficiency factor allows for a correction to the perimeter room lighting and/or cooling energy equipment consumption due to facade and building factors, as follows:

- reduced illumination in perimeter rooms x 0.9
- reduced cooling due to perimeter shades x 0.9
- increased cooling due to non insulated roof or raking ceiling x 1.1
- increased cooling due to no external shades x 1.2.

These factors supplement the LLO (Figure 10) rating tool Table 1 nominal scores.

Operation load factor (OLF)

Column J, K and L record the semester normal and weekly after hours times for operation, as noted from building management interviews, plus the non semester times of building use. The operation load factor is the proportion (%) of actual hours to total hours per annum (8,760). The estimated total hours are shown in column N (hours). The extent that this has been achieved is evidenced by the +/- 10% correlation with the Campus Infrastructure Services supplied electrical consumption data.

4.9 LLO tool and functional areas

The LLO defines functional areas (academic or activity spaces or rooms) as may be seen in Table 8 below and Figure 10 (the actual LLO tool). The LLO functional area benchmarks in Table 8 are simply summed to provide the arithmetic mean value, to be used in the LLO tool table 2 , Figure 10. Even though there is considerable spread between the differing buildings, for most benchmarks it was considered valid not to use some form of regression analysis to appear to achieve a more accurate result, but to include all records due to the actual variation in surveyed area situations for a small sample size.

Table 8 Energy consumption benchmarks in kWh/m² pa for LLO functional areas

BUILDING ID		LLO TOOL FUNCTIONAL AREAS kWh/m²/annum									
		1 OFFICE (NABERS)	2 LIBRARY	3 COMPUTER LAB LESS THAN 15	4 LECTURE ROOM LESS THAN 15	5 KITCHEN CAFE	6 WORKSHOP	7 TEACHING LABS (U/G)	8 RESEARCH LABS (P/G)	9 IT SERVER ROOM (NOT IN 1	10 OTHER
A28		Not collated during audit									
F12		87	52	141							
H12			143								
J13		Not collated during audit									
J02		Not collated during audit									
D02		Not collated during audit									
F19		Not collated during audit									
A29		Not collated during audit									
G04		122		438	183	924	65	121	132	420	175
J03		136							42		
A18		70	108	110	45			63			
A09		77			209	531					91
D04					239						
G09	AC	261				1007					130
	NO AC	157									
H69		29		415						7725	94
		101									361
A23		91				259	979			2123	53
G01	AC	201		363	180	303	97			722	357
	NO AC					267					
G12		199									
M02		226	135	206	363	1589		162		1011	62
F10		108	338	248	181	86				205	29
A35/36		99	54	227	133		187	163	144	839	113
F07		93		442	307	887		29	290	262	53
B22		156	279	232				146		802	136
FUNCTIONAL AREA MEAN VALUES		130	158	282	204	650	332	124	152	1567	138

Source: 24 University of Sydney building audits 2009 to 2014, illustrating the energy consumption benchmarks for the LLO functional areas disaggregated from the whole of buildings.

It is important to note that G08 protocols (TEFMA 2011, updated 2015) classify areas as building area, usable floor area and gross floor area. Of these, gross floor area has been selected as it more accurately includes potential energy use (kilowatt hours per square metre) (TEFMA 2011, updated 2015). Moreover, different organisations adopt different nomenclature for the same basic use function as shown in Table 9 below. Because this variety of functional areas have a wide variation of energy consumption intensities it is important to achieve a standard definition of space use. The LLO tool began its development in 2009 prior to the 2011 emergence of the G08 group. The LLO audit exercise began by determining the ten most significant and generic space use types in tertiary education buildings. The more 'types' the more complex the audit exercise would be.

Table 9 Nine functional (activity) areas in tertiary education buildings identified by various organisations

G08 room codes		LLO room codes		HEEPI (UK)	GREEN STAR (AUST)	LAB 21 (USA)	CIBSE F Table 20.1 (UK)	CBECS
				MATCHED TO LLO ROOM CODES				
1	office	1	office	admin/ support	office admin	chemical		Admin office
					common spaces			
5	library & learning	2	library			physical	library natural vent	
							library air conditioned	
3	specialist teaching & learning	3	computer lab	library		biological		
				computing/ maths				
2	teaching & learning	4	lecture room	teaching	teaching & learning	chem/bio	lecture room science	library
6	general facility	5	commercial kitchen			others	catering fast food	
							catering bar/ restaurant	
4	ancillary space	6	workshop					
3	specialist teaching & learning	7	teaching lab	labs (physics/eng)	dry labs	chemical		laboratory
				labs (med/bio)	wet labs	physical		
				labs (chem/sci)		biological chem/bio		
3	specialist teaching & learning	8	research lab					
5	library & learning	9	IT server rooms				science laboratory	
6 7	6,7. Residential	10	other	sports centre	gymnasium1		residential - halls of residence	College/ university
				residence	car parks		residential, self catering flats	

Source: Energy benchmarking room descriptions from: G08 Space Planning and Management - Space Data User Guide version 3 (TEFMA 2011, updated 2015), LLO tool (2015), Green Star V1 Education rating tool (Green Building Council of Australia 2009), Lab 21 (2014), CIBSE Guide F Table 20.1 (CIBSE 2012), Commercial Building Energy Consumption survey (2003), HEEPI Table 1 (2004, p. 4).

The selected LLO functional areas were subsequently refined through a number of research iterations to provide data significance for energy intensity in the Australian university context, and to more accurately capture actual use and practice.

As can be seen, differing research groups and university administrations have a variation of categories and descriptions and definitions of these spaces as they are identified for differing purposes. The resulting range of variation in data formats are such that they "varied so much that it wouldn't be possible to use them accurately to complete the annual TEFMA Benchmark Survey" (*Baseline Energy*, Department of Climate Change and Energy Efficiency 2012, p. 86).

There are various published energy consumption benchmarks, CIBSE Guide F chapter 20 Building Benchmarks, including for education, HEEPI energy performance indicators (Aug 2004) , Green Star Education V1 standard practice benchmark document, and CBECS - National median energy use intensities by building type (see appendix 6) based on differing criteria and which are suitable as guidance material for Australian campus buildings, but not directly as a disaggregated prediction tool.

A key conclusion of this study is it is necessary to resolve functionally distinct building types and end uses to understand or model accurately the energy consumption of tertiary education buildings across Australia. Precinct level estimates (such as average energy intensity across an entire campus) represents a useful starting point, but such estimates mask very significant diversity in the energy intensity of different building types (*Baseline Energy*, Department of Climate Change and Energy Efficiency 2012, p. 94/09 universities).

Bruhns et al. (2011, p. 31) in their review of energy benchmarks for display energy certificates noted that "in any event there is certainly a need for an addendum to current guidance in order to explain the recommended way to allocate benchmark categories to buildings on sites".

4.10 Summary of buildings audited

The photographs in Figure 13 on the following pages depict the 24 buildings audited and summarised in Table 4 and were taken by the researcher during 2009 to 2014 as part of the documentation for and supervision of the DESC9111 audit process, or have been sourced from the University of Sydney website.

WILKINSON BUILDING (G04)
GFA 11,313 m²
6 level building, era 1960s,
administration, lecture rooms,
studios, workshop, cafe

MANNING HOUSE (A23)
GFA 3,952m², 1914 heritage listed 2 level brick
building, with 4 level extension (1999)
bar, cafe, offices

EDUCATION ANNEXE (A36) GFA 1,738m²

EDUCATION BUILDING (A35)
GFA 10,138 m², 9 level single brick
building over concrete frame built
1993, lecture theatres, computer rooms,
dance & drama studios, offices connected
by elevated walkways to buildings A26 & A23

HOLME BUILDING (A09)
GFA 6,760 m²
5 level heritage listed, masonry student facility and
recreation, with contemporary extensions - dates
from 1913

Figure 13 Summary of 24 buildings audited at the University of Sydney

CARSLAW BUILDING (F07)
GFA 17,022 m²,
8 level masonry & glass building

lecture, tutorial, laboratories, offices and staff rooms

WENTWORTH BUILDING (G01)
GFA 10,399 m², 1960s masonry & glass structure, 6 level building with extensions in the 1970s and 1990s.
Student lounges, computer rooms, retail level, cafe, loading dock, cool rooms, plant rooms

SCHOOL OF NURSING (M02)
GFA 12,527 m²,
comprising 4 buildings, 1920s heritage listed converted (1980s) factory, buildings A & C - 5 levels, B & D - 2 levels car parks, library, research, tutorial rooms, cafe, lecture theatres

ELECTRICAL ENGINEERING (J03)
GFA 9,396 m²
11 level masonry, 1960s building, laboratories, administration, workshops

BRENNAN MACALLUM (A18)
GFA 7,500m²
9 level (refurbished 1990) masonry building administration, faculty staff in cellular offices, general access computer laboratories

PNR & OLD SCHOOL (J02)
GFA 3,931 m²
3 level, 1950s masonry building,
library, lecture rooms

LINK BUILDING (J13)
GFA 3,844 m²
5 level, 1980s masonry building
administration, lecture rooms, laboratories

VICTOR COPPLESON/QEII (D02)
GFA 1,219 m²
2 level, 1940s masonry building
administration, small laboratories

TRANSIENT BUILDING (F12)
GFA 2,216 m²
2 level, 1946 fibro building
administration, laboratories, faculty

ECONOMICS AND BUSINESS (H69)
GFA 6,844 m²
2001, 6 level contemporary masonry building
computer labs, post grad research, offices

BOSCH 1A (D04)
GFA 2,009 m²
2 level, 1950s masonry lecture rooms,
cafe and seminar room

AQUATIC CENTRE (G09)
GFA 6,647m²
2 level 1990s masonry aquatic centre, sports facility, shops, cafe, basketball and squash courts

VET CONFERENCE CENTRE (B22)
GFA 1,939 m²
3 level masonry building, conference rooms foyer, offices, service rooms, classrooms, meeting rooms, lecture theatre

PHYSICS ANNEXE (A29)
GFA 1,1738 m²
4 level, 1960s light construction, administration and laboratories (since demolished and rebuilt)

PHYSICS BUILDING (A28)
GFA 8,404 m²
5 level, 1940s masonry building – administration, teaching rooms, laboratories

EASTERN AVENUE AUDITORIUM (F19)
GFA 3,046 m²
4 level, lecture rooms only, 1990s building

SERVICES BUILDING (G12)
GFA 6,529 m²
1920s heritage factory building, double brick construction, 3 level offices, with contemporary roof modifications for plant room spaces

LAW BUILDING (F10)
GFA 30,069 m²
2009 built, concrete frame, steel and high performance glass facade, 2 basement car park levels with 6 floors above, lecture and seminar rooms, computer labs, library, cafe, offices

4.11 Summary and conclusion

The research methodology employed an energy audit of 24 University of Sydney buildings by room by room survey. The results are summarised in Table 4 and Table 8 are used in the composition of the LLO tool in Figure 10 (also Appendix 1).

The rationale for the selection of room by room audit, the process for completing the audits with a description of the training of the graduate students including meeting with and feedback from building management (and Campus Infrastructure Services staff and management) are described in detail.

The accuracy of the LLO spreadsheet annual energy consumption estimates meeting the Campus Infrastructure Services supplied electricity data within plus or minus 10% validates the process and is principally due to the quality of the graduate students carrying out the audit, the high level of cooperation from Campus Infrastructure Services and building staff, and establishing and using fabric efficiency, operational load and equipment load correction factors applied with some professional judgement to the room by room survey data. This reasonable and appropriate accuracy, considering the difficulty in obtaining accurate operation data, as opposed to anecdotal opinions, leads to confidence in the output, which are the functional area energy consumption benchmarks shown in Table 8. The other factor affecting accuracy is that of space, area and room classification, which presents ongoing issues on which TEFMA and the university administrations are constantly reviewing.

The reviewed literature, particularly CIBSE TM54 (2013), reinforces as a comprehensive and current guide and critique of past practice the methodology practices in DESC9111 which commenced prior to this CIBSE publication.

Due to the inherent variability in the process and use which the results will be applied, the benchmarks in the LLO tool itself (Table 2 in Figure 10) are presented as a range, as is also done in CIBSE Guide F (2012). They are by no means absolute. The selection from low, medium to high is done by means of scores (LLO Table 1 in Figure 10).

The scores are a result of independent variables, validated by the Design Building/Energy Plus simulation study (Appendices 2, 3 and 4) to have an above 7% effect on the annual energy (electrical) consumption of a typical campus functional area. The significant variables are operational, equipment loading and use. The selected single exterior north aspect, when variations to glazing and shading were modelled (simulation LLO tool spreadsheet Appendix 3) indicated less than 5% variation to the modelled annual energy consumption and on this basis were not included in the LLO tool.

The aim of the methodology was to produce a better tool for benchmarking energy use in tertiary educational facilities. The disaggregation of a building into common functional areas is fundamental to the use of the tool.

The tool is designed to be simple to use by building faculty staff and to be a reasonable compromise between simplicity and accuracy, providing useful results.

As the LLO scores and benchmarks are directly derived from the University of Sydney audited buildings, validated by the plus or minus 10% comparison with Campus Infrastructure Services consumption data, by a process of disaggregation, the reverse process to re-aggregate the functional areas into whole building, will logically follow.

These researched benchmarks for common functional areas in University of Sydney campus buildings are a database to build on, with additional data from other buildings and other campuses, to improve the accuracy of the tool, for the purposes outlined in the six research aims in Chapter 1.

5 Discussion

5.1 Selection of energy efficiency measures

This section of this chapter discusses selection of energy efficiency measures. The reason for this discussion is that eventually the information from energy benchmark comparison will lead to optimum allocation of resources for energy management, so an introduction to this topic is appropriate, thus exposing some barriers to the use of the concept of disaggregated buildings: functional areas and energy efficiency.

Information from the *Energy Savings Action Plan* (University of Sydney 2008) and the audits by students in the graduate subject DESC9111 (Obrart 2014) on the energy consumption patterns within typical campus buildings show 60% for HVAC and 20% for lighting. It is rational that application of energy efficiency measures, across a whole campus or within whole buildings, should start with equipment systems which consume most energy (Thumann et al. 2009 and Knapp 2006). Note that fire and emergency services are not included in this consideration. The *Baseline Energy* report (Department of Climate Change and Energy Efficiency 2012, p. 93) provides similar consumption by energy source data.

5.1.1 Lighting

Interior lighting

The recent advances of lighting technology and controls (NSW Office of Environment and Heritage 2012) are readily and cost effectively applied to part and whole of campus buildings, preferably during refurbishment where light fittings would often be replaced, but also during the normal maintenance and repair cycle.

New fluorescent tubes for old

Current strategy generally involves labour and materials to replace existing T12 luminaries, starters, controls and tubes with new technology T8 or T5 and their controls. There are a myriad of light fittings for both space and task functions in buildings. The majority of space lighting has been provided by fluorescent tubes with room or area, manual switching, or alternatively, automatic timed building or area controls via a large range of technologies, from simple timers to complex building management systems.

Energy saving lighting

Any annual equipment energy consumption is a product of instantaneous power (watts) x time in use. The two possibilities for energy savings are:

- reduced equipment consumption, which can be provided by T8 and T5 type space lighting at below 9 w/m² compared to old T12 with ballast at around 15 w/m² for similar lighting effect which assumes the lighting intensity is fit for purpose and the space is not over lit.
- reduced operation hours, which can be achieved by improved controls to switch lighting off when not required for occupant use, by zoning the lights by area to accurately reflect the occupancy requirement (functional area) and by automatic timers or movement sensors, to further reduce the use for a specified area not in use and requiring artificial lighting.

- substitution of existing lighting and luminaires by current technology LED with appropriate controls

5.1.2 Cooling, heating and ventilation

The cooling, heating and ventilation energy management situation is much more complex than lighting because of the multiple options for existing equipment and systems in existing campus buildings and because of the range of design performance from contamination exhaust to select boardroom comfort, to large lecture theatre relief conditions.

The issues for consideration in applying energy efficiency measures are:

- to what extent the building is fully or partially naturally ventilated or air conditioned
- the air conditioning systems installed in the building, either campus central energy plant, building central plans, or local zone, room or area units in the building, or most likely a combination of all of the above.

The ventilation systems within the building can be categorised as:

- amenities exhausts (toilets, rest rooms)
- car park ventilation (exhaust and supply)
- make up air to air conditioning systems or occupied non naturally ventilated areas for regulation compliance (the operation of these systems is prescribed in regulations)
- specialised or local contaminant ventilation, fume cupboards, laboratory equipment and similar.

The energy savings technologies commercially available vary widely. The relationship of annual electrical energy consumption being the product of equipment consumption (watts) x time (hours) presents a wide variety of opportunities for equipment and operations.

Firstly, it is important to ensure installed equipment is operating efficiently. If the equipment is grossly inefficient compared to current equipment, carry out a cost effective study to examine replacement. Otherwise, employing the appropriate professional skill level, closely review the control and operation of all significant equipment to examine how cooling, heating and ventilation functions can be delivered with reduced energy consumption. Timer control, time and extent of operations play a vital role in energy reduction.

Secondly, most energy audits and the literature readily identify equipment running 24/7 or times when it is not required. Most energy audits also identify major equipment including chillers, boilers, pumps, fans, air handlers and condensing units not operating at the manufacturers rated maximum efficiency. As a result of energy audits and various expert reports and industry conferences, campus administrations are all to some degree involved in building by building improvements, according to budget, local politics and prioritised course of action from the energy efficiency experts.

Functional area considerations are missing. What is not being recognised by the energy experts is that to provide functionality and operating efficiency to distinct functional areas in buildings, a most useful method is to not focus on a whole of campus strategy, but to identify the individual buildings and common functional areas (Knapp 2006 and Thumann et al. 2009). This is identified by CIBSE Guide F (2012) as a "bottom up approach".

Providing valid comparisons as to what is proven to work and what does not is the role of management, based on "start local, proceed to universal".

5.2 Application of energy efficiency measures to existing buildings

The literature detailing the selection and application for retrofitting of energy efficiency equipment systems is vast, including from manufacturers, consultants and installation contractors. The energy efficiency industry has been active in buildings for decades with countless studies of successful applications as described in conference papers and journals. The international and Australian sustainability and energy rating schemes discussed earlier including LEED (US), BREEAM (UK), Green Star and NABERS have websites listing design and operation successes in reduced energy consumption, by some benchmark rating system, generally a normalised rating of kWh/m^2 pa.

The difficulty for campus buildings and energy managers for diverse tertiary education buildings is that the major energy consuming systems are also diversely applied and controlled, generally due to historic, political, funding and management issues, not present in most commercial buildings. For example, the highly energy consuming ventilation, cooling, heating, refrigeration systems vary from sophisticated central energy plant distributing energy to connection buildings by some mechanical and electrical infrastructure, to simple local generic split air conditioning, similar to a domestic room system, which was the origins of this type of simple cost effective equipment. Energy sources may vary from utility grid to local generation.

Faced with this complexity, most consultants, experts from outside the faculty, target their efforts to and recommendations for installation of energy efficiency measures to meet the general facilities management requirements of maximising financial return, which equates to minimising capital outlay for maximum energy saving, over some defined time period, generally two to five years (Beggs 2009, CIBSE Guide F 2012).

The recommendations of multiple campus energy audits initially focus on what appear to be the current major 'culprits', large systems operating inefficiently, and cost effective savings are readily achieved. This is because each functional area has a differing need for services and hours of operation to provide functionality and operability, depending on the mechanical and electrical systems installed and their controls.

Functional areas

The omission in this work is often due to the lack of attention to the performance of services (mechanical and electrical) in functional areas with reduced functionality as the result. For example, when a central air conditioning plan or lighting system serving all or many functional areas of the total building is 'performance optimised' the availability of performance, the functionality in a particular area, may be compromised due to the expense or technical difficulty of providing controls for that specific (functional) area.

A more informed choice would be to first identify from the functional areas, with their likely local mechanical and electrical systems within the building and then target the energy efficiency measures ranked by rate of return.

For total building or large area lighting systems, area controls of time of operation and intensity (such as selective switching or dimmers) and use or movement sensors may contribute to overall building energy efficiency by reducing total consumption, but at the expense of local functionality.

Cooling, heating and ventilation systems for total building or large areas to suit the original building layout at the time of installation, may have control strategies for time of operation and local capacity or environmental controls which can be optimised for total building energy consumption, but can lead to poor functionality in local functional areas due to lack of available local controls.

In the building energy management profession, there is the observed phenomenon that there is a trade off between overall consumption and energy efficiency and the level of performance and functionality provided. Three examples are provided. Firstly, after hours extended use of open access computer laboratories (open to all students) with related lighting, air conditioning and powered services, may require elements of the complete building services to be operating, which serve areas other than and additional to the computer laboratories, because the building controls do not allow these other non-functioning areas, to be turned off.

Secondly, after hours use of laboratories may have special equipment required to operate 24/7 for some process or experiment. But the local lighting and air conditioning for the safety and comfort of a few researchers including a special process may be a very expensive exercise, if due to lack of local functional area controls, extensive sections of the building, including areas for access to the laboratory, also have to be operating.

Thirdly, a large lecture theatre operating for extended hours, with a wide variation in occupancy, may have different cooling systems requirements for 500 people in early afternoon compared to only 50 people in late evening. The question is, does the cooling system, if serving the building, have controls with adequate sensitivity to provide demand controls to suit this variable duty. If local functional area controls are not provided, excess energy use or lack of comfort is the likely result.

When applying energy efficiency measures to existing buildings with existing systems, use a "bottoms up" approach. Survey what functionality the energy consuming mechanical and electrical services need to provide, at what capacity and for what time interval, then select and apply energy efficiency measures.

5.3 Standing losses: baseline energy use

5.3.1 Standing losses

What happens overnight? Why is energy used to such a relatively high level during vacation and shut down? A very significant result from the campus energy audit surveys is the identification of 'standing losses' or 'baseline energy' electrical consumption at an unexpectedly high level.

Study of the Campus Infrastructure Services electricity consumption patterns kWh over time periods clearly indicates that at operational times when buildings are essentially unoccupied, there is an electrical consumption substantially above the minimum expected use for:

- required emergency 24/7 services
- security
- 24/7 refrigeration
- specific research laboratory equipment access and use requirements.

From the audit team reports detailing building room by room survey including identification of energy consuming equipment and proposed operating times, it can be shown what equipment should be running 24/7 or after hours, and the difference between what the consumption 'should be' and what is in the utility data. The difference is caused by 'waste', that is unauthorised or erroneous running of equipment.

Many campus buildings have this standing loss consumption of the order of 25% to 35% of the normal operating peak, indicating substantial wastage. Anecdotal information from experienced energy industry practitioners, including Chris Bloomfield of Energy Action (2015) and Bruce Precious (2015), indicates 5-15% is a likely range of standing electrical consumption for commercial office buildings. The literature does not indicate researched data on standing losses. A serious question is why there is such a high level of potential waste in campus buildings.

Table 4 indicates a range of base load consumptions from CIS data, for the 24 buildings audited.

5.3.2 Examples of standing losses

During a 2009 presentation to the University of Sydney Energy Reduction Working Group, which included the CEO, several Deans and Campus Infrastructure Services staff, and also at the 2010 TEFMA presentation, there was wide amazement at the graphical representation of the standing losses, and the potential waste of energy represented, as shown in the figures below.

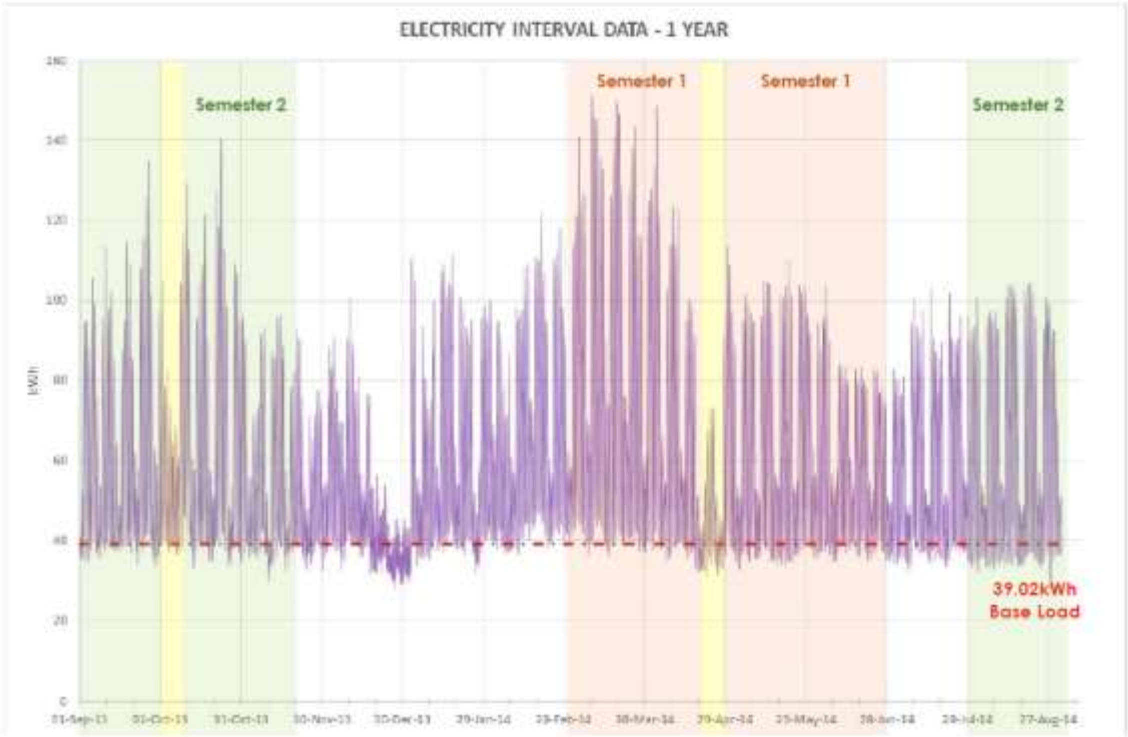


Figure 14 Carslaw Building annual electricity consumption September 2013 to August 2014
Source: Campus Infrastructure Services.

Table 10 Summary of annual electricity consumption for Carslaw Building

Electricity consumption	Semester period		Non semester period		
	Semester 1 & 2	After hours only	Winter	Summer	After hours only
Minimum kWh	32.87	29.68	35.54	31.06	29.76
Maximum kWh	151.24	98.92	103.52	111.40	84.35

Source: Figure 14 above.

Table 10 summarises Figure 14 with minimum and maximum electricity consumption in semester and non semester period. Campus Infrastructure Services consumption data indicates a minimum base load or after hours consumption of approximately 39 kWh. While it is expected that the peak consumption loads vary according to the seasonal requirement for cooling and heating and with the semester variations in student occupancy, and the time of day use schedule, what is most notable is the relatively high standing or base load of approximately 39 kWh, as a proportion of the summer (140 kWh) or winter (103 kWh) peaks. What is extraordinary is the constancy (24/7) of the approximate 39 kWh base load, through all days of the year. Contributions to the 39 kWh can be individually selected from the room by room survey data and include:

- refrigeration equipment
- exit, emergency and access lighting
- essential IT equipment for security
- essential equipment for research
- computers in all computer labs.

However, the overall impression is that significant equipment is running after hours, in fact 24/7, contributing to energy waste.

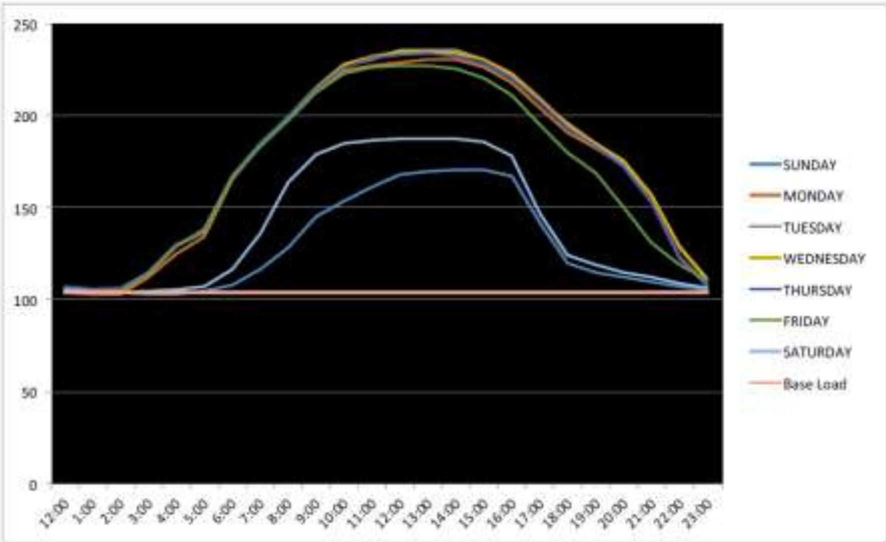


Figure 15 Law Building average power use by day of the week
Source: Campus Infrastructure Services data.

Campus Infrastructure Services consumption data indicates a minimum after hours or base load consumption of approximately 104 kW. The average base load is summarised in Table 11.

Table 11 Summary of base load for Law Building

Base load building estimation	**kW**
Car park lighting	4
Car park fans	16
Switch room cooling	4
Comms room air conditioning	13
Exit lighting	0.4
Cafe refrigeration	53
Refrigeration and vending machines	1
Chiller pumps and heaters	0.37
Fire systems and panels	1
BMS, cameras and lighting controls	7
Building lighting	2
Total per annum	**104**

Source: DESC9111 room by room spreadsheet A-P.

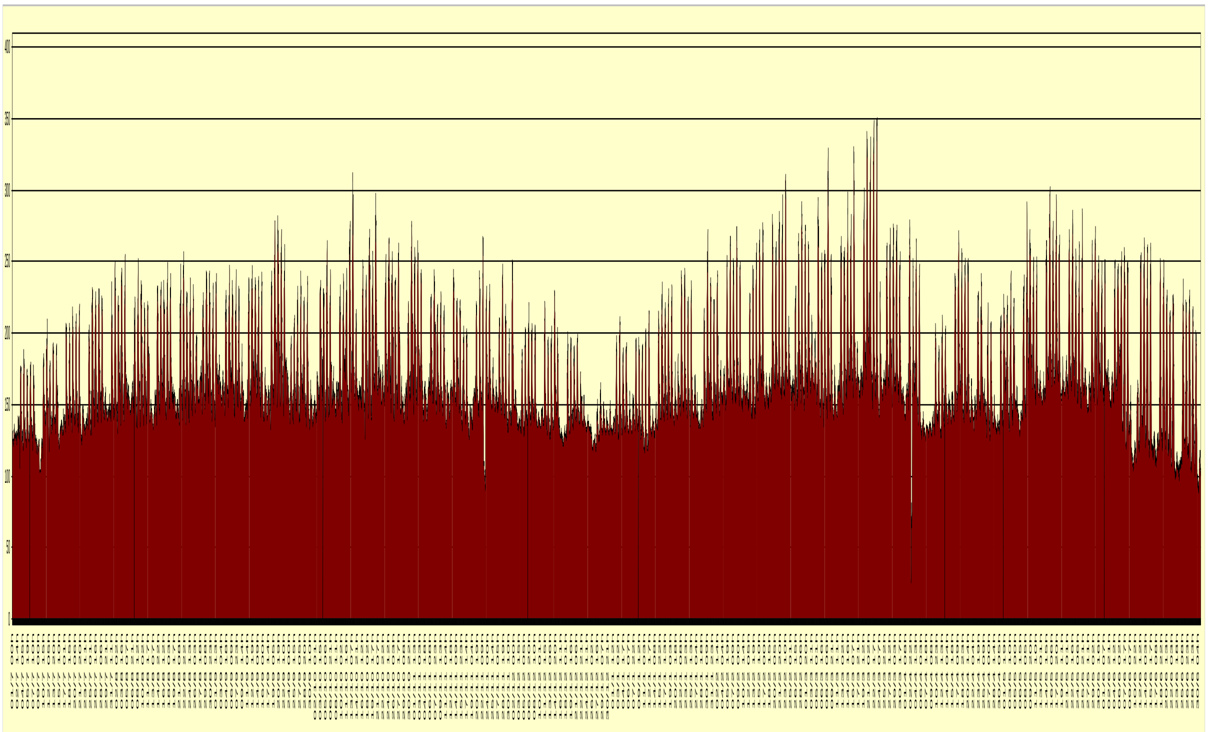


Figure 16 Wilkinson Building daily electricity use profile from June 2006 to July 2007: Y axis kW versus X axis time
Source: Campus Infrastructure Services.

As indicated from the Campus Infrastructure Services consumption data, the peak loads vary over the twelve months, with seasons and occupancy. Again remarkable is the relatively large standby base load of approximately 120 kWh, 24/7, irrespective of the use, time and operations of the building. This base load is extraordinarily high, particularly as in this building, there is no medical or refrigeration process or research, the only refrigeration is local bar refrigerators and the cafe refrigeration equipment. The implication is that computer laboratories server rooms, mechanical plant and lighting are running in semester, non semester and even vacation times.

An energy audit for the Edward Ford Building at the University of Sydney was completed in November 2011 by Greenkor Engineering auditor Alex Koncar. This study shows the Campus Infrastructure Services provided electrical energy consumption data indicating a baseline of approximately 40 kW 24/7, with peak power around 120 kW in summer and 1,240 kW in winter. For the Christmas period 15 December 2010 to 7 January 2011, base load was reduced to around 30 kW.

A series of audits completed by consulting engineers UMOW Lai for Macquarie University in 2014 of over 50 campus buildings (Esmore 2015) show in part for example:

- building M0A baseline approximately 110 kW, peak 300 kW
- building E4B baseline approximately 20 kW, peak 80 kW
- building C5A baseline approximately 40 kW, peak 180 kW.

5.3.3 Summary

All of the above referenced buildings indicate base loads well above a normal commercial building base load consumption of 5-15%. This indicates that detailed studies into the makeup of the base load, by an audit in periods of non use is required, with the LLO spreadsheet as a guide to where to investigate. This study needs to be done by trained technical staff, with a background in mechanical and electrical services and their controls and documentation for operation of and understanding of the operations of the building.

Resulting from these studies, a schedule can be prepared showing energy consuming equipment and normal operating hours, divided into categories:

- services required for functionality of the operations in the building such as essential process IT and laboratory equipment (operating for a specified short term project or 24/7)
- services for occupant food refrigeration
- services for cafeteria refrigeration, beverage and food
- services which are running for no reason contributing to the health and safety of occupants or functional process win a building, for example, office and IT equipment not being used, cooling, heating, lighting, ventilation to areas not being used.

The criteria has to be 'why, when and for what capacity can this equipment be turned off'. Energy efficiency measures can be applied, selected from:

- management of the operations of the building
- equipment – more efficient plant substitution
- technology – improved controls.

The measures can be applied firstly to functional areas, and secondly to whole of building systems, to achieve a reduction in non essential waste of energy consumption. The potential savings from minimising this base load potential waste in tertiary campus buildings could be very large. If the evidence in the University of Sydney 24 building sample and the Macquarie University building sample (3 out of 50) is repeated across multiple campuses, that is after hours, (building not in use) energy consumption remains of the order of minimum 25%, then appropriate application of the philosophy "switch off when not in use" (taking into account essential, process and emergency services which in commercial buildings account for about 15% or less of the peak consumption) could be reasonably expected to reduce the existing building energy consumption by the order of 10%.

5.4 Barriers to identification of functional areas for energy efficiency in existing buildings

The majority of tertiary campus energy managers have ongoing programs for energy efficiency. This can take the form of routine building maintenance, cost saving programs, which may include replacement of light fittings and fitting local timers to equipment, or major capital expenditure programs, generally planned years in advance, organised by the central facilities office, which can include complete equipment and systems replacements. Another opportunity for improved energy efficiency is when refurbishments or renovations for change of use in existing buildings are planned.

None of the above processes are necessarily related to functional areas, or specifically to efficient energy use in functional areas.

The above existing building renovation and maintenance processes are generally faculty or department targeted to suit management and budget requirements, not focused on functional areas to facilitate energy efficiency. Identification of and provision for services controls for functional areas is the key for energy efficiency focus. For example, for a local manual system; where is the light switch and where is the thermostat, and for a remote automatically controlled system, who programs and maintains the logic. Treating major energy consuming plant and systems (cooling, heating, lighting) is an obvious priority, for which there is ample information and expertise.

5.4.1 Energy audits and existing buildings

Part of the recommended result from an energy audit such as Obrart (2014) at the University of Sydney and Esmore (2015) at Macquarie University is a prioritised schedule of recommended energy efficiency recommendations including projected energy savings, cost of the energy efficiency measures and a ranking in order of simple pay back period, that is, the ratio of estimated cost divided by the annual saving of the energy efficiency measures, given in years. The rationale for this logical presentation is that for cost budget planning, the most effective, earliest return on investment energy efficiency measures can be readily selected.

However, unlike new buildings (under say five years use), most existing campus buildings have been in use for decades and have had multiple refurbishments, involving installation of new mechanical and electrical services, often on a functional area basis, not the whole of building, as new area uses and budgets permit. This means many of the existing and upgraded systems which account for the significant energy use, mechanical and electrical services, and new laboratory or process equipment, to retain their functionality in their areas being served, require energy efficiency measures aimed at functional areas, not the whole of building. For example, for typical existing buildings, new central access computer laboratories have dedicated supplementary air conditioning systems, lighting and controls. Refurbished academic and administration offices also have supplementary air conditioning and upgraded lighting and controls.

The general whole of building energy audit does not respond to these common functional area opportunities for energy savings (application of energy efficiency measures) while retaining local service and functionality including special times of use. A major omission is that application of energy efficiency measures needs to be simultaneously targeted at the complete building system, in parallel with consideration of the functional areas involved, to retain functionality.

5.4.2 Non technical barriers

The principal non technical barrier is management resources of time and attention from the central administration organising a refurbishment to the local faculty, department or functional staff in charge. It appears always difficult when consulting the stakeholders to control an ever expanding wish list to meet approved budgets for costs and time available.

The audit of 24 University of Sydney buildings confirms extensive experience from similar work outside of the university that correct information on the required functionality of mechanical and electrical services, hours and extent of operations, on a room by room basis, is difficult to obtain accurately. For instance, the professor is not available, senior staff may not accurately know how a faculty is used or meant to be used, and staff who know do not have any authority to make decisions. Questionnaires may not be answered accurately and face to face is expensive on time. To overcome lack of information, catering for all eventualities with complex controls is usually costly.

The issue of non technical barriers is also a significant focus in the development of the LLO tool which is an information generating methodology, intended to guide building management towards cost effective applications of valid technical solutions to increased energy efficiency.

5.5 Application to new buildings and future energy ratings

What should differentiate the discussion of application of energy consumption benchmarks leading to information for targeting the application of energy efficiency measures is that new buildings should be specified to include comprehensive energy consumption data collection, reporting and monitoring hardware and software, flexibly configured so that rooms can be mixed and matched to functional areas, which have an academic or departmental relevance in the whole building for responsibility, utility, charging and management.

The National Construction Code/Building Code of Australia building regulations (Section J8, Facilities for Monitoring) have limited requirements, but an informed client will instruct consultants in the design team to ensure a full suite of monitoring and verification equipment is installed to allow ongoing comparison, year by year, for management and control of energy management systems and comparison with valid energy benchmarks and similar buildings.

Anecdotal evidence and conference presentations (such as AIRAH's pre loved building conference 2013 and the future of HVAC conference 2013) indicate in the commercial sphere, trained energy managers monitor data within systems and functional areas of buildings, weekly or monthly, with exception reporting of performance not in accordance with a predetermined energy budget. This is useful for new or in the design stage buildings, but to retrofit such control or monitoring technology into older existing building, requiring in most cases, extensive rewiring of the building, is unlikely to be cost effective apart from a complete building refurbishment, including mechanical and electrical services. Additionally the staff expertise to monitor, analyse, report and action any non conformances is expensive and requires a high level of expert training.

The driver for this level of maintenance and improvement for building energy in commercial buildings is the commercial necessity to maintain and improve energy ratings, such as NABERS or Green Star, with a quantifiable outcome, calculated in rental return improvements and/or requirements to meet a tenant's contracted energy efficiency target, which must be annually verified. This is not the case with campus buildings, although some campus sites claim sustainability ratings (Bond 6 star) under defined circumstances.

Aside from the Macquarie University program discussed in Chapter 3 (which is not a G08 university), which is most comprehensive and involves considerable retrofit works, responses from the G08 universities indicate that generally existing buildings will have energy efficiency managed on an area by area and building by building basis, as funds are available. This leads to the rational application of a benchmarking tool, like LLO, for functional area comparisons in existing buildings, as a primary energy management tool in lieu of a capital intensive program to install controls, wiring and sub metering.

5.6 Conclusion

This leads to the central purpose and application of this research. When a campus building is disaggregated, and LLO tool benchmarks applied (or equivalent), it becomes evident which areas should be prioritised for cost effective application of energy efficiency measures, due to the predicted energy consumption for each area, which in turn leads to the cost effective selection and application of energy efficiency measures to all or part of the building.

6 Conclusions

6.1 Introduction

The literature review clearly identifies the gap in the knowledge about energy use and management of tertiary education buildings, despite the importance of managing energy use for both cost and sustainability. Historical energy consumption data, per campus or per building, does not provide information useful to identify, predict, manage and reduce energy consumption in mixed use existing campus buildings, due to the widely differing energy intensities, uses, hours of operation, and building architecture in the functional or academic areas in buildings. This leads to a gap in knowledge in managing energy use in tertiary education buildings.

Existing energy benchmarking policy and tools indicate that for improved understanding and analysis of energy consumption in tertiary campus (and office buildings in general), further breakdown of existing categories used for collection of data is required. Breakdown into additional more descriptive and meaningful types of area, by use and operations, particularly for mixed multiple use buildings, very typical of a tertiary campus, would be useful. Data by functional area is required.

Year on year comparison has limitations

The literature concludes strongly that the existing inconclusive energy consumption data has principal value in allowing comparison of same building energy year on year, with comparison with peers secondary. However, the year on year comparison ignores the relative efficiency of the subject building. There could be year on year improvement but this may mask a building operating very inefficiently, with considerable waste, possiby detected by survey and audit, or by comparison with benchmarks that are available, even if inaccurate.

Disaggregation is the key

When this research including energy audits in 24 University of Sydney buildings commenced in 2009 and continued to the end of 2014, based on the graduate subject DESC9111 Energy Management in Buildings, and the literature review relating to energy benchmarks in broadly, commercial buildings and specifically, existing tertiary buildings, the principal intent was to collect data to populate the LLO tools with functional area consumption benchmarks to assist in prediction of disaggregated functional areas, allowing to the building of prediction of the energy consumption for whole of building.

As the project evolved and the inherent inaccuracies and difficulties in collecting actual data became apparent, which is confirmed by overseas institutions involved in building energy data over many years and the published reviews of the available data, it became apparent that the identification, disaggregation and use of functional areas in tertiary buildings is the significant value of this work, with the accuracy of the actual benchmarks being secondary.

The accuracy of the LLO tool benchmarks are adequate considering their purpose as an estimation tool, taking into account the source of data, and that ongoing energy audits throughout the tertiary campus and building population will provide additional data to populate the LLO tool, working towards increased accuracy as the sample sizes increase.

The research has developed the LLO tool, based on data collected at the University of Sydney from 24 buildings and validated from the method of data collection as recorded on the LLO spreadsheet A-P and comparison with the Campus Infrastructure Services utility energy. The six aims of this research have been addressed as follows.

6.2 Disaggregation of data

The research has provided meaningful disaggregation of data allowing the establishment of functional area energy benchmarks as detailed in Table 8 of this thesis, from the comprehensive room by room energy audit and survey process of complete buildings. These functional benchmark areas (see LLO tool Figure 10) have been selected on the basis that they have significantly different energy intensities and use patterns requiring differing control strategies to deliver functionality and energy efficiency. The functional areas are an aggregation of room types which are listed in the G08 space management dictionary (TEFMA 2011, updated 2015).

6.3 Functional area benchmarks

Functional area benchmarks are presented in the LLO tool (Figure 10). The presentation of the benchmarks for selection across the range low, medium, high is consistent with variations in data collection. These benchmarks indicate the likely range of energy intensities across functional areas, allowing a useful comparison of common areas across diverse buildings, indicating relative energy efficiencies.

6.4 Validation of the concept of functional areas

This literature and research has validated the concept of disaggregation into functional areas in campus buildings for identification and control of energy in buildings. The literature in multiple locations supported the lack of disaggregated data to make energy benchmarking useful in comparing mixed use buildings energy efficiency resulting from lack of detail in existing data. The research shows, by comparison between the 24 buildings audited and the 14 buildings from the *Energy Savings Action Plan* (University of Sydney 2008), the relative energy consumptions normalised per m² gross floor area are so diverse when compared to actual knowledge of these buildings and their operations, that the whole of building figures are of no practical use for energy efficiency comparison. Disaggregation into common functional areas within these diverse buildings will provide useful comparisons data.

6.5 Selection and application of energy efficiency measures

While the research has not improved the actual selection and application of typical energy efficiency measures, it has provided information such that when the LLO tool is used appropriately it will indicate what functional areas should be prioritised for the investigation and application of energy efficiency measures.

For any functional area in an existing campus building, the selection of the cost effective energy efficiency measure from the wide range of industry technology available is complex, as indicated in NSW Office of Environment and Heritage (2012) and AIRAH's *Guide to Best Practice Maintenance and Operation of HVAC Systems for Energy Efficiency* (2012).

The solution can range from installation of simple local timers or movement sensors to confine equipment end use to actual time of use through more complex central automatic controls, programmed and wired to serve the functional area through extension to or replacement of existing equipment and systems, with more energy efficiency systems and their controls.

It should be noted that University of Sydney's *Energy Savings Action Plan* (2008) and Macquarie University include recommendations for energy efficiency measures to be retrofitted to existing buildings, generally whole of buildings, not functional areas which misses an important opportunity.

6.6 Identification of base load consumption

The research has identified base load consumption, that is the standing minimum electrical consumption for virtually 24/7, arising out of nocturnal hours, weekends and vacation times. The University of Sydney and Macquarie University energy audits identified base load consumption over 25% of the average peak levels while anecdotal commercial building experience indicates 10-15% maximum is more likely.

If this is the case, and excluding equipment essential for university building functioning over and above a typical commercial building with similar regulatory lighting and occupant required refrigeration, there may be a minimum of 10% peak load dissipated in wastage by end use services running when not required.

6.7 Appropriate aggregation of data

The issue of aggregation of building energy consumption is identified in the literature review as a significant problem in the use of benchmarking. The problem has arisen due to the institutions that established benchmarking databases well over ten years ago who were faced with the difficult trade off between accuracy and simplicity. The result was to limit to some extent the commercial building descriptions which can be entered and the means of interrogation of the database to determine to what extent a subject building and its services has a meaningful database match. The value of benchmarks, that is continuous improvement by valid comparison, is challenged by what is a valid comparison. Additionally, year on year building energy comparisons overlook the possibility that a building may be grossly inefficient and energy wasteful, masked by small year by year improvements.

Currently, an Australian tertiary education campus containing a large and diversified portfolio of buildings only has partial individual whole of diversified buildings electrical energy consumption data which can be used to provide whole of building non comparable energy consumption benchmarks.

However, the missed opportunity demonstrated by this research is that data disaggregated into common functional areas in diversified buildings provides a much more accurate picture of energy consumption, allowing cost effective selection and application of energy efficiency measures and re-aggregation of common functional areas into dissimilar diversified whole of building, for a superior comparison, leading to further energy efficiency. The contribution of this research is to highlight a way forward supported by the findings of the literature search.

This issue is for campus management authorities to find the resources to extensively sub meter functional areas for real time and accumulate energy consumption data, or, as a less accurate but more cost effective alternative, to energy audit and compile functional area consumption benchmarks, and to use a development of the LLO tool concept to enable the continuous improvement by valid comparison.

6.8 Future research directions

The research indicates several future research directions.

Consider other benchmarks

Investigate the possible applicability of existing energy benchmarking tools, such as CIBSE TM22 or Green Star Education V1, with some modification, to provide a more accurate tool to develop further functional area benchmarks, which may be more comprehensive but acceptably simple to use compared with the LLO tool (Figure 10).

Weight utility charges

Liaise with university administrations to ascertain to what extent the LLO functional area benchmarks can assist in determining the space and utility charges applicable to faculty and department areas, possibly by means of some weighting to supplement allocation of expenses per annum based on gross floor area or usable floor area as is commonly used.

Conduct building surveys

Liaise with the G08 group to investigate the use of selected energy audits, commencing with high priority energy intensive functional areas in service intensive equipment (SEI) buildings, as a start to a disaggregated functional area program, to benefit studies of energy efficiency and application of energy efficiency measures.

Reduce base load consumption

Develop with the co-operation of G08 facilities and energy managers a ‘waste watch’ process for ongoing monitoring of the inexplicably high base load electricity consumption using continuous improvement by benchmarking. This process would require survey and audit by experienced technical staff to identify unauthorised, uneconomic equipment operation.

Extend NABERS

Investigate the establishment of a new category such as university campus buildings for the NABERS energy rating system. Anecdotal discussion with Dr Paul Bannister, one of the originators of the AGBR (now NABERS) rating system, indicates that an impediment to supporting a NABERS rating for university campus buildings is the unacceptably wide diversity of campus building stock (compared to office buildings), and the relatively small sample size. Possibly both of these objectives could be overcome by the use of common functional areas in diversified campus buildings, providing order of magnitude larger sample. Note that the NABERS rating (precommitment or actual) is the basis for a Green Star sustainability rating, as the required energy input.

If a NABERS rating could be established for a majority functional area of a campus building, with quantification of "non core activities" to be excepted, the value for TEFMA or the G08 and any campus, would be an industry wide system of recognition for energy efficiency in (whole or part of) a campus building, allowing a year by year energy reduction process (or not) to be identified and successful energy efficiency measures (EEM) to be applied as appropriate.

References

AIRAH (2012) *Industry Survey Report – NABERS rating tools*, www.airah.org.au/imis15_prod/Content_Files/UsefulDocuments/AIRAH_Industry_Survey_Report%20_NABERS_rating_tools_Feb12.PDF

AIRAH (2012) *AIRAH response to the draft National Building Energy Standard Setting Assessment and Rating Framework*, www.airah.org.au/imis15_prod/Content_Files/UsefulDocuments/Response_to_draft_building_Framework%20final.pdf

AIRAH (2012) *Guide to Best Practice Maintenance and Operation for HVAC Systems for Energy Efficiency*, www.airah.org.au/imis15_prod/Content_Files/UsefulDocuments/DCCEE_HVAC_HESS_GuideToBestPractice2012.PDF

AIRAH (2013) *Submission Green Star – Design And As Built Consultation Paper*, www.airah.org.au/imis15_prod/Content_Files/UsefulDocuments/AIRAH_Submission_Green_Star_Design_As_Built.pdf

AIRAH (2013) The future of HVAC conference, Melbourne, 13-14 August 2013.

AIRAH (2013) Pre loved buildings conference, Sydney, 13-14 November 2013.

AIRAH (2013) Submission: National Energy Efficient Building Project (NSEE) issues paper submission by AIRAH, www.airah.org.au/imis15_prod/Content_Files/UsefulDocuments/NEEBP.pdf

Al-Shemmeri, T. (2011) *A Work Book for Energy Management in Buildings*, Chichester, Blackwell Publishing Ltd.

APPA: Leadership In Educational Facilities (2015) *Facilities Performance Indicators,* www.appa.org/Research/Fpi/Index.Cfm

ASHRAE (2015) Building Energy Quotient, www.buildingenergyquotient.org/

ASHRAE (2015) ANSI/ASHRAE/IES Standard 100-2015, *Energy Efficiency in Existing Buildings,* Thomson Reuters (Scientific), Chicago.

Australian Building Codes Board, National Construction Codes (2015) Building Code of Australia, volume 1, www.abcb.gov.au

Australian Building Codes Board (2015) Energy efficiency link, www.abcb.gov.au.

Beggs, C. (2009*) Energy Management and Conservation* (2nd Edition), Elsevier, Oxford, United Kingdom.

Bloomfield, C. (2015) Emails to Alan Obrart on energy efficiency, December 2015.

BREEAM *British Research Establishment Environmental Assessment Method* (2015) BREEAM, www.Breeam.Com/.

Bruhns, H., Jones, P., Choen, R. and Bordass, B. (2011) *CIBSE Review of Energy Benchmarks for Display Energy Certificates – Analysis of DEC,* www.Cibse.Org/Knowledge/Cibse-Technical-Symposium-2011/Cibse-Review-Of-Energy-Benchmarks-For-Display-Ener

Campus Assist Online (2015) *Space Planning and Management Editing Space Data User Guide,* version 3.

Carbonbuzz (2015) About Carbonbuzz, www.Carbonbuzz.Org/About.Jsp

Carbon Trust (2015) Further and higher education, Training colleges and universities to be energy efficient, Sector Overview
http://www.carbontrust.com/media/39208/ctv020_further_and_higher_education.pdf

CIBSE (2006) *TM22: Energy Assessment and Reporting Methodology,* Chartered Institute of Building Services Engineers, UK.

CIBSE (2008) *TM46: Energy Benchmarks,* Chartered Institute of Building Services Engineers, UK.

CIBSE (2011) *Review of Energy Benchmarking for Display Energy Certificates*, Chartered Institute of Building Services Engineers, UK.

CIBSE (2012) *Guide F: Energy Efficiency In Buildings*, Chartered Institute of Building Services Engineers, UK.

CIBSE (2013) *TM54 Evaluating Operational Energy Performance of Buildings at the Design Stage*, Chartered Institute of Building Services Engineers, UK.

Collins, D. (2011) *University of Sydney Utility Monitoring Part 2 Development (3) G08 Metering Analysis,* Cundall, Sydney.

Council of Australian Governments (2010) *National Strategy on Energy Efficiency*, Council of Australian Governments, Canberra.

Department of Climate Change and Energy Efficiency (2010) *National Building Energy Standard Setting Assessment And Rating Framework, National Strategy on Energy Efficiency,* public discussion paper, Commonwealth of Australia, Canberra.

Department of Climate Change and Energy Efficiency (2011) Letter of Introduction, www.acts.asn.au/wp-content/uploads/2011/12/Letter-of-introduction-FINAL.pdf

Department of Climate Change and Energy Efficiency (2012) *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia, Part 1 Report,* Department of Climate Change and Energy Efficiency, Canberra,
www.Industry.Gov.Au/ENERGY/ENERGYEFFICIENCY/NON-RESIDENTIALBUILDINGS/Pages/Commercialbuildingsbaselinestudy.Aspx

Department of Industry (2013) *Case Study Energy Efficiency at University of Queensland,* Canberra, Eex.Gov.Au/Files/2014/10/Uq-Case-Study.Pdf

Department of Industry Innovation and Science (2015) *Energy White Paper,* Canberra, http://Ewp.Industry.Gov.Au/.

Engineers Australia (2010) *Draft ACT Sustainable Energy Policy 2010-2020,* www.Engineersaustralia.Org.Au/Sites/Default/Files/Shado/Representation/Government%20Submissions/2010/Draft_Act_Sustainable_Energy_Policy_2010-2020_March_2010.Pdf.

Escriva-Escriva, G., Alvarez-Bel, C. and Penalva-Lopez, E. (2011) New indices to assess building energy efficiency at the use stage, *Energy and Building* 43, 476-484.

Esmore, S. (2015) Macquarie University energy audits – using big data, Tertiary Education Facilities Managers Association (TEFMA) Annual Conference, Wollongong.

Green Building Council of Australia (2009) *Green Star Education V1 Standard Practice Benchmark Summary,* www.Gbca.Org.Au/Green-Star/Rating-Tools/Green-Star-Education-V1/

Green Building Council of Australia (2010) *Green Star Education V1 Energy Calculator Guide* rev. B1, www.gbca.org.au/uploads/226/1762/Green%20Star%20-%20Education%20v1%20Energy%20Calculator%20Guide%20-%20Revision%20B.1%20270110.pdf

Hart, C. (1998) *Doing a Literature Review*, Sage, London.

Higher Education Environmental Performance Improvement (HEEPI) Project (2004) *Results of the HEEPI HE Building Energy Initiative 2003-4,* www.goodcampus.org/files/files/15-Final_report_on_03-4_HEEPI_benchmarking_v2[1].doc

Hong, S. (2015) Benchmarking the performance of the UK non domestic stock: a schools case study. A thesis submitted for the degree of Doctor of Philosophy, University College, London.

Hong, S. and Steadman, P. (2013) *An Analysis of Display Energy Certificates for Public Buildings, 2008 to 2012,* www.Bartlett.Ucl.Ac.Uk/Energy/News/Documents/CIBSE__Analysis_Of_Display_Energy_Certificates_For_Public_Buildings_.Pdf

Hyde, R., Prasad, D., Blair, J., Moore, R., Kavanagh, L., Watt, M. and Schianetz, K. (2007) Reviewing benchmarking approaches for building environmental assessment (BEA) tools – rigour versus practicality, *Conference,* National University of Singapore, Department of Architecture, School of Design and Environment, Singapore.

Kempener, R. (2007) *The Low Energy High Rise Project – Literature Review*, Warren Centre for Advanced Engineering, University of Sydney, Sydney.

Knapp, A.F. (2006) Lean energy audits – rethinking common management practices of multi building energy audits, *Strategic Planning for Energy and the Environment*, 25 (4), 71-78.

Kuzcek, E. (2014) *Research space within the G08, Extent and costs?,* Report for Tertiary Education Facilities Managers Association (TEFMA) (confidential).

Labs for the 21st Century (2015) Labs21, Labs21benchmarking.Lbl.Gov/

Lee, W. (2011) Benchmarking use of building environmental assessment schemes, *Energy in Building* 45, 326-334.

Leifer, D. and Obrart, A. (2013) Sustainable retrofitting of commercial buildings, in *Energy Performance Rating Systems: How International and National Policies and Rating Systems Leverage a Methodology for Retrofit,* Routledge, London.

Liddiard, R., Wright, A., Marjanovic-Halburd, L. and Ruskin, A. (2008) *Review of Non Domestic Energy Benchmarks and Benchmarking,* https://Scholar.Google.Com.Au/Scholar?Q=)+Review+Of+Non+Domestic+Energy+Benchmarks+And+Benchmarking&Hl=En&As_Sdt=0&As_Vis=1&Oi=Scholart&Sa=X&Ved=0ahukewili-2_3c3jahxklkykhcxydpiqgqmigtaa

Montgomery, R. and Wentz, T. (2014) Exploring ASHRAE's Building Energy Quotient Program, *ASHRAE Journal*, 56 (5), 62-69.

Morton, E. (2012) A robust method for benchmarking energy performance in multi-tenant office buildings, *BRE Trust Review 2012,* 40-42.

NSW Office of Environment and Heritage on behalf of Commonwealth, state and territory governments (2015) National Australian Built Environment Rating System, NABERS, www.nabers.gov.au/

NSW Office of Environment and Heritage (2015) Annual Report 2014-15 National Australian Built Environment Rating System, NABERS, www.nabers.gov.au/

NSW Office of Environment and Heritage (2012) *Energy Saver Energy Efficient Lighting Technology report*, NSW Office of Environment and Heritage, Sydney.

Obrart, A. (2009) *DESC9111 University of Sydney Campus Infrastructure Services FADP – Industry Partners, Staff and Student Training Programme of Energy Audit, Survey & Preparation of Energy Management Plan for Selected Campus Buildings*, University of Sydney, Sydney.

Obrart, A. (2014) *DESC9111 Energy Management In Buildings*, Faculty of Architecture, Design and Planning, University of Sydney, Sydney.

Obrart, A. (2015) Poster presentation, Tertiary Education Facilities Managers Association (TEFMA) Annual Conference, Wollongong.

Precious, B. (2015) Emails to Alan Obrart on energy efficiency, December 2015.

Property Council of Australia (2015) *Guide to Office Building Quality Matrix,* www.propertycouncil.com.au

Property Council of Australia (2015) *Office Benchmarks*, www.propertycouncil.com.au/Web/EventsServices/ResearchData/Retail_Office_Benchmarks/

Ruyssevelt, P. (2014) *CIBSE Carbonbuzz Analysis*, University College London Institute.

Schofield, J. (2014) ENERGY STAR building benchmarking scores: good idea, bad science, *2014 ACEEE Summer Study on Energy Efficiency in Buildings,* Pacific Grove, California, 17-22 August 2014.

Schofield, J. and Richman, G. (2015) Results of validation tests applied to seven ENERGY STAR building models, *International Energy Program Evaluation Conference*, Long Beach, California, 11-13 August 2015.

Sharp, T. (1998) Energy benchmarking energy use in schools, *ACEEE Summer Study on Energy Efficiency in Buildings*, 3, 305-316.

Spielvogel, L. (2015) Emails to Alan Obrart on energy efficiency, November 2015.

Standards Australia (2014) *AS/NZS 3598 Parts 1,2 & 3 (2014) Energy Audits,* Standards Australia International, Sydney and Standards New Zealand, Wellington.

Tertiary Education Facilities Managers Association (TEFMA) (2011, updated 2015) G08 Universities Space Management Data Dictionary Version 3.0 Jan 2015.

Tertiary Education Facilities Managers Association (TEFMA) (2013) G08 SEI Vs GP Space Project.

Thumann, A., Younger, W. and Niehus, T. (2010) *Handbook of Energy Audits*, Fairmont Press Inc., Lilburn.

University of NSW and Energetics *(*2011) *Revision of AS/NZS3598 Energy Audits,* www.industry.gov.au/energy/Documents/energy-efficiency/energy-audit-standard-consultation-paper.doc

University of Sydney (2008) *Energy Savings Action Plan (2008)*, University of Sydney, Sydney.

US Environmental Protection Agency (2015) *Energy Star,* www.**energystar**.gov/

US Green Building Council (2015) *LEED V4 Certification Rating Tool,* www.Usgbc.Org/Leed

Ward, I., Ogbonna, A. and Altran, H. (2008) Sector review of UK higher education energy consumption, *Energy Policy,* 36 (8), 2939-2949.

Appendices

1. The LLO Tool

2. Final Simulation Study LLO Rating Tool version 3

3. Final Simulation Study LLO Rating Tool spreadsheet

4. Supplementary Assumption notes to Final Simulation Study LLO Rating Tool

5. DESC9111 Energy Management in Buildings (2014) selected class notes.

6. Benchmark guides;
   A. CIBSE Guide F chapter 20 Building Benchmarks, including for education
   B. HEEPI energy performance indicators (Aug 2004)
   C. Green Star Education V1 standard practice benchmark document
   D. CBECS - National median energy use intensities by building type