Sustainable Laboratories for Universities and Colleges

- reducing Energy and Environmental Impacts

Based on a HEEPI benchmarking workshop
held on 26 April 2007

27 July 2007

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Executive Summary

In April 2007, a workshop was held with energy and laboratory managers from the higher education sector to calculate energy performance benchmarks for university laboratories and identify features that were contributing to the buildings' energy performance. Data from 45 laboratories at nine universities was collected. Benchmarks were calculated for four laboratory types: bioscience (with and without secure facilities); chemical science; and physical engineering laboratories.

The main conclusions are that while ventilation and cooling are critical to significantly improved energy performance in laboratories, there are many areas where reductions in energy consumption can be made. A whole life approach, which considers all the components of a laboratory's energy system over the long term, is the most effective way to optimise energy performance. This, coupled with the involvement of lab users, safety and facility managers, from the outset of a lab design or refurbishment process, through to energy management and maintenance can help to reduce energy consumption and costs, and enhance safety.

1. Introduction

Laboratories consume large quantities of energy and water – often more than three or four times the rate for offices on a square metre basis. Annually 40-50% of their total electrical consumption is typically consumed by fans for the ventilation systems, while an additional major component of peak loads can come from chilling air or water to cool spaces or equipment. There is growing evidence that some of this high utilities consumption – and its associated operating costs (which are not just energy and water bills, but the capital, maintenance, and other expenditure on supply and distribution capacity) - can be avoided through effective design, without compromising, and indeed enhancing, safety. However, few UK laboratories are achieving this, especially in higher education.

To examine the issues, and current performance, in greater depth, HEEPI convened a practitioner workshop at the University of Warwick on 26 April 2007. The workshop was based on residence energy consumption data provided by participants, using HEEPI's energy and CO_2 benchmarking tool, CE-Benchbuild.[1]

2. Benchmarking Results

Participants were asked to provide data on fossil fuel and electricity consumption and basic building data for their laboratories during the period 1 August 2004 - 31 July 2005. In a few cases where this data was not available, universities submitted data for 1 August 2005 - 31 July 2006, or calendar year 2006.[2]

In total nine universities submitted data on 41 laboratories[3], comprising:

1. 9 medical/bioscience (with secure facilities)
2. 15 medical/bioscience (without secure facilities)
3. 7 chemical science
4. 9 engineering/physical science labs
5. 1 other

[1] See www.heepi.org.uk/benchmark.
[2] Although data from the two years are not strictly comparable, it was felt that the difference in degree days between the two years (between 4-8%) (see Appendix 1) would not dramatically affect the results, based on weather alone.
[3] Four engineering/physical laboratories were added subsequently.

Discussion was held on the individual laboratories, to correct any problems in the data, and to identify the features that were contributing to the buildings' energy performance. The main points from that discussion are summarised below. The actual figures provided for the meeting have been updated following clarification of queries, and submission of additional data. The final benchmarks for four of the laboratory categories, calculated on the basis of confirmed data, are given in Table 1 below. Table 2 provides benchmarks from a previous round of HEEPI benchmarking for comparison.[4]

Table 1: Provisional Lab Benchmarks based on 2004-05 and 2005-06 data

Laboratory Type	**Typical Practice Energy Performance (kWh/m²)**		**Good Practice Energy Performance (kWh/m²)**		**Best Practice Energy Performance (kWh/m²)**	
	Fossil Fuel	Electricity	Fossil Fuel	Electricity	Fossil Fuel	Electricity
All Labs	296	312	135	227	79	143
Medical/bioscience (with secure facility)	397	362	(198)	(227)	100	245
Medical/bioscience (w/o secure facility)	289	300	196	242	130	109
Chemical Science	353	367	(244)	(333)	177	327
Physical Engineering	177	196	(104)	(86)	119	52

Table 2: Existing HEEPI Lab Benchmarks based on 2001-02 data

Laboratory Type	**Typical Practice Energy Performance (kWh/m²)**		**Good Practice Energy Performance (kWh/m²)**		**Best Practice Energy Performance (kWh/m²)**	
	Fossil Fuel	Electricity	Fossil Fuel	Electricity	Fossil Fuel	Electricity
Medical/bioscience	256	325	121	250	75	177
Chemical Science	175	264	(108)	(203)	97	156
Physical Engineering	148	130	92	93	15	66

Figures in parentheses are where there is strictly insufficient data (sample <15) to calculate lower quartile, but are provided for indicative purposes.

Points to note from these tables include:

- The high energy consumption of chemical science labs, largely due to the high levels of ventilation associated with fume cupboards
- The presence of a secure facility greatly increases the energy consumption of medical/bioscience laboratories
- The generally lower total energy consumption figures associated with physical engineering laboratories compared to other laboratory types, though electricity consumption is proportionately higher

[4] Results of the HEEPI HE Building Energy Benchmarking Initiative 2003-04, August 2006 www.heepi.org.uk

- The increase in benchmark values of all facilities, but especially chemical science and physical engineering laboratories, compared to 2001-02 data.

The increase in values is almost certainly explained in part by differences in sample size and composition. Some relevant factors which probably vary between the samples are the percentage of total building area which is actually occupied by laboratory space (as opposed to offices, teaching spaces etc.), the age of the building (as newer ones tend to have higher specifications), and occupancy hours. However, the discussion suggested that it also reflects some real changes in recent years, including higher occupancy hours (more 24/7 operation), ever-increasing amounts of energy-intensive analytical and IT equipment and higher health and safety standards (for example, more bioscience laboratories have higher level containment facilities (see Appendix 2) which requires greater levels of air filtration, and therefore energy consumption.

These differences suggest that the output figures should be seen as indicative only, and used with caution. Given that the level of quality control, and face-to-face discussion, associated with them is very high, they also suggest that figures from other sources should also be treated with great caution. The only way to achieve more accurate figures would be a much larger sample size, and more sub-categories of different kinds of laboratory, e.g. by containment level or occupancy hours.

3. Discussion Points

The main points that emerged from the discussion have been grouped into themes as follows:

Modern labs are more energy-intensive
The workshop data suggests that recent labs are more energy-intensive than older ones. This is true even though older laboratories generally have poor insulation, single glazing and other energy-inefficient features. The main reason appears to be higher levels of services (heating, ventilation, and in-lab electrical equipment) and higher occupancy hours. Other reasons are because energy efficiency measures have been value-engineered out, or poor commissioning.

Involve all users in design and management
The importance of involving users and facility managers at the outset of a lab design or refurbishment process was stressed. For example Newcastle University have conducted pre-design workshops with all users for its Devonshire laboratory and refurbishment of one of its chemistry laboratories.[5] Consultation with user groups, including the estates and maintenance engineers, is essential to challenge assumptions about the design, and reduce post-occupancy problems. By contrast the original design for an architecturally landmark lab at one university, undertaken without the involvement of facility managers, turned out to be unserviceable and had to be redesigned at great cost. The final design was not optimized for energy efficiency and had high energy consumption levels as a result.

Commitment of lab and building managers to energy efficiency is a vital component of reducing energy use. Low energy use at a number of University of Oxford labs was thought to be attributable to the commitment of the building/lab management team.

The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) require employers to identify and classify (zone) areas of the workplace where explosive atmospheres may

[5] See presentation by Steve Jackson and Mike Dockery, A Chemistry Lab Refurbishment Project – Introducing the Ethos of LABS21. see www.heepi.org.uk under events.

occur and take measures to remove those risks.[6] This often results in the need for additional ventilation and because university safety officers tend to err on the side of caution, it may result in unnecessarily high energy consumption. Micro-analysis of the risks is needed, which requires estates, safety and lab managers to work closely together. Mike Dockery noted that BSI and HSE are considering the 'containment banding' of fume cupboards to relate to the functional risks (types and quantities of material).

Labs are wind tunnels

Air changes are often being over-specified for the cooling and ventilation loads which are needed – often by people who do not fully appreciate the energy consumption implications of the decision. The result is that fan energy can often account for 50% or more of total electricity consumption. Reducing air change rates can therefore be of great benefit, as can use of variable speed drives. The selection of fans is very important: it is possible to get substantial electrical energy improvements through specification of more efficient fans.

For Class 2 microbiological safety cabinets in a containment level 2 environment it was suggested that recirculating air through high efficiency particulate air (HEPA) filters rather than ducting directly outside would drive down the air change rates, and hence energy consumption. However, there is a background of safety concerns with any recirculated air in labs and some university safety officers or HSE inspectors may insist on double- HEPA's for the recirculated air, or may prohibit the approach outright.

The siting of filters (for high containment labs) is also important. There is a tendency to reduce the size of HEPA filter banks to reduce capital costs but this leads to a large pressure loss across the system which increases operating costs. It is therefore important to look at whole life costs of ventilation systems.

Reducing energy associated with air handling units (AHUs) and fume cupboards is often the biggest potential saving in chemical science laboratories. Heat recovery is an attractive option for AHUs but carries with it capital on-costs and operating/maintenance challenges. Reducing the size of AHUs to reduce capital costs often requires silencers to be added, which increases resistance and hence operational energy costs. Again, whole life costs of decisions need to be considered at the outset.

Risk assessment of fume cupboards is vital

Fume cupboards are typically specified on the basis of standard face velocities – typically 0.5 m/s. However, face velocities are not based on scientifically grounded standards, but 'rules of thumb' which have developed over the years. The argument for high face velocities is an intuitive one that assumes improved safety, but in practice this is not necessarily so as high velocities can contribute to turbulent conditions at certain sash locations. An aerodynamically effective fume cupboard design operating at an appropriate face velocity is the key to the twin objectives of safety and enegy efficiency. The new European Standard (BS EN 14175, released on 01/05/06 and completely replacing BS 7258), gives methods for producing safe containment based on function and location, rather than an empirical 'catch-all' standard for face velocity. On-site testing, rather than type testing is essential for safe containment. It was noted that having a face velocity of 0.5 m/s was no defence in law in the event of an exposure incident. Instead it was important to understand the chemicals being used, the hazards associated with those chemicals, and the exposure risk. Education of fume cupboard users was also stressed, as was the need to re-evaluate exposure risk when the research activities changed.

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[6] Regulation 7 of DSEAR requires employers to classify places at the workplace where explosive atmospheres may occur into hazardous and non-hazardous areas. Hazardous areas are classified into zones: 1 1, 2, 20, 21 and 22. http://www.hse.gov.uk/electricity/atex/definitions.htm

In addition to increased safety resulting from on-site testing, this can also result in significantly reduced energy consumption. Reducing face velocities from 0.5 to 0.3 m/s reduces energy consumption by 40%. Several university laboratories have adopted face velocities of 0.4 m/s and one university was intending to trial a system of 0.3 m/s. It was suggested that ductwork could be designed on the basis of running at 0.3 m/s, but be sized to accommodate 0.4 m/s to provide a future-proofing/flexibility margin.

Caution should be taken when specifying fume cupboards. It was noted that many manufacturers are making claims for low velocity fume cupboards when they are simply reducing the flows on conventionally designed fume cupboards. The University of Newcastle which specified high levels of containment with low face velocities for its fume cupboards, used Clean Air Ltd fume cupboards for the Devonshire building, and Gloria Artec fume cupboards for the Bedson Building refurbishment.

Good controls and metering are vital

Well managed control systems can make a significant difference. Doing this requires a high level of metering, which is already a requirement of new build and major refurbishments. Measures that universities are taking to fine-tune their building management systems (BMS) include:

- Variable speed drives
- Adjustment of temperature according to outside temperature
- Use of free cooling wherever possible
- Introduction of wider dead bands to reduce the heat/cool/heat cycle
- Application of additional night setbacks - one university used a setback regime for its chemistry laboratory of 10.30 p.m. to 7.30 a.m., which it was gradually increasing, in addition to reducing the diversity (ie number of fume cupboard in operation)

High air change rates have a particularly severe effect on energy consumption when there is no heat recovery in place. This is often excluded or taken out of designs because there is pressure to reduce capital costs but this can be a false economy as the energy savings achieved give a relatively quick pay-back However, one expert noted the difficulties of achieving effective recovery, both because the available energy is sometimes exaggerated, and because the engineering solutions can be difficult to achieve, e.g. avoiding cross-contamination of incoming air. Heat pipes may be the best means of overcoming these problems.

In one lab, overly complex control philosophies, and a lack of good manuals resulted in energy use twice that of the predicted design. In the case of complex buildings where there is a heavy reliance on the BMS, more education is generally needed on how the building is used.

It was noted that few universities had received log books when refurbishments were undertaken.

Managing chillers

Air conditioning is a large component of many laboratories energy consumption, particularly where there is a proliferation of split systems for comfort cooling. However there is often poor integration of heating and cooling systems – in several buildings studied these “fight each other” so that over-cooling results in the heating coming on and vice versa.

A case study conducted by Bristol University showed that 20-25% reduction in energy can be achieved through a number of cooling measures including introduction of a lagtime, taking account of outside temperature, compression amplification and variable speed drives on pumps.

Measures to reduce cooling loads include:

- Use of free cooling wherever possible
- Variable speed drives for centralised AHUs and pumps
- Use of chilled beams
- Taking account of outside temperatures
- Compression amplification
- Introduction of a lag time

Bristol University also won a green gown award for it structured approach to air conditioning. See the case study in Section 4 for more details.

The issue of whether chillers needed to be so large was raised. It was suggested that sizing the chiller to provide cooling for the 3-4 hottest days of the year was not cost effective, and many occupants wouldn't notice the difference if it were sized slightly smaller.

Reconfiguring space and services
Some buildings are being heated and cooled as a whole, rather than just the parts which actually need it (e.g. secure facilities which form only a relatively small part of the total floor space but have to be heated or cooled 24/7). Reconfiguring space to concentrate heavily-serviced activities into particular areas of the building can greatly reduce energy consumption.

Similarly some services which are on a ring main are often provided to meet the highest common denominator. For example many labs produce nitrogen from compressed air at high pressures (typically 2000 psi). Some synthetic chemistry application require very high purity nitrogen (>99.999% nitrogen) whereas other applications can tolerate higher levels of impurities. Producing the nitrogen for the highest level purity for all uses can increase energy consumption unnecessarily. At one university they used a lower pressure nitrogen generator (150psi) and apply a local booster and filter at the point where a higher purity was needed. This was both cheaper and more energy efficient. Flexibility in the system is also required as research groups and their needs change. One point to note is that there is a high degree of variance in the operating pressures of the different nitrogen generators on the market.

The use of liquid nitrogen was also suggested as an alternative option to on-site generation. Although this is more expensive, contains high levels of embodied-energy, and requires additional technical support, it was suggested the whole life costs of using liquid nitrogen versus on-site production would be worth assessing.

Importance of maintenance
Poorly maintained equipment is a major source of energy inefficiency. For example if air filters are not cleaned regularly, resistance and thus energy consumption is higher.

Maintenance contracts should be checked to ensure they are not merely inspection contracts, which rely on individual departments for action.

Managing plug loads
Plug loads are often much higher than anticipated, plus can increase rapidly if energy-intensive equipment is installed without warning. In one case, this actuality resulted in a need to upgrade power supplies and a transformer, at considerable expense.

The presence of large numbers of fridges and freezers create a high heat load and consequent need for cooling (these accounted for a quarter of the heat load in one building studied). Measures to reduce the energy consumption associated with fridges and freezers include:

- Specifying only very energy-efficient appliances, e.g. 'A'-rated fridges. As these sometimes cost no more than lower rated appliances, this should be a cost effective measure.
- Installation of Savawatt controls on their fridges. In one university this resulted in a significant reduction in baseload electricity consumption. However, Savawatt controls may not be cost-effective in their own right, as one analysis showed paybacks on new fridges were as long as 10-15 years, and many existing fridges would be at the end of their life before payback. They may be useful where there is a need to reduce power load in a building for capacity reasons.
- Centralising low temperature (-80C) freezers in dedicated cold rooms – but has the disadvantages that this is not popular with departments, and some cold rooms may be over-cooled.
- Controlling the frequency of door opening
- Proper siting of freezers (ie not next to incubators)
- General maintenance – repairing damaged door seals, condenser cleanliness and keeping the evaporator clear – was found in one university to save 30% energy.

There was little information on the relative efficiencies of different types of –80C freezers.

Steam boilers
Steam boilers were found to be very high energy users – in one lab steam boilers accounted for one third of the gas consumption. Although electric autoclaves can be used, steam is essential for use in autoclave sterilisation in level 3 containment labs. None of the workshop participants had any suggestions for reducing energy associated with steam boilers. Post-meeting note: a US EPA laboratory in Washington reduced energy and water usage associated with autoclaves by utilising the autoclave standby function and installing water reducing valves.[7]

Specific Points on Labs with Secure Facilities
It was noted that labs which had open cage racks often had air change rates as high as 15-20 air changes per hour. Individually ventilated cages (IVCs) were recommended both on energy grounds (as the high air change rates are confined to a smaller space) and because they provide better conditions for animals (by allowing customised air change rates per cage) and researchers (by reducing levels of airborne allergens). For this and other reasons, they can be cheaper than conventional husbandry, on a system basis. Several laboratories have convinced Home Office inspectors that the approach is advantageous.

Other points
Other points made in the discussion were:

Very few labs have undertaken post occupancy evaluations, even though this can highlight remediable faults, and provide useful learning for subsequent developments.

The exact level of plant control – very narrow tolerances for temperature, for example, will result in much more cycling on and off and therefore higher energy consumption.

Good lighting management is a cost-effective way to reduce energy consumption.

[7] http://www.epa.gov/greeningepa/pubs/archives/june05.htm

4. Example – Chilling and Cooling at the University of Bristol

Bristol University's energy consumption for cooling in all its buildings – including labs - has been rising. A new approach to providing chilled water has been piloted successfully the highly serviced Dorothy Hodgkin laboratory. A detailed survey revealed that chilled water was responsible for 36-40% of normal electricity consumption. To reduce this, a Liquid Pressure Amplification (LPA) pump was added to the main chiller. This creates a constant outlet pressure, which in turn reduces compressor load and enables the plant to operate constantly within optimum design parameters, regardless of ambient conditions. The more uniform load is also expected to extend the lifespan, and require fewer replacement units and parts for, the chiller. In addition, the Building Energy Management System (BEMS) was modified to optimise loading, and variable speed drives were installed on the primary chilled water pumps. The total cost of the project was £71,950.

During the summer of 2006 electricity consumption for the building was reduced by 10%, equivalent to annual savings of up to £30,000 and 145 tonnes of CO_2. The payback of the project was therefore 2.4 years. Subsequent improvements have increased savings to 18% of the December 2005 level. The project also raised staff awareness about the high costs of chilled water. Following its success, the Energy & Environmental Management Unit has prepared a case study and commissioned a refrigeration specialist to review all of the University's 22 chilled water systems with a view to replicating the project across the University. A key finding of the report was the importance of maintenance.

In parallel, the University has also initiated a review procedure for all new requests for air conditioning in laboratories, and other buildings. This includes the application of a specially developed decision tree to ascertain if special cooling needs are present, and a heat gain tool to analyse whether the load is sufficient to require cooling. If cooling is necessary, a new specification ensures that equipment is energy efficient, and is properly installed.

Acknowledgements

HEEPI would like to thank all the participants that provided data or attended this workshop and for their analysis of the issues which formed the basis of this paper. Special thanks to Mike Dockery, Health & Safety Laboratory, and Phil Wirdzek, International Institute for Sustainable Laboratories, for their expert input at the workshop, and for the University of Warwick for hosting the event.

Appendix 1: Comparison of Degree Days in 2004-05 with 2005-06 in selected regions[8]

Location	Degree Days			
	Aug 04-July 05	Aug 05-July 06	Difference 04/05-05/06 (%)	20 year average
1. Thames	1724	1832	+6	1832
2. South East	2024	2131	+5	2102
4. South West	1687	1816	+8	1750
5. Severn Valley	1848	2016	+8	1802
6. Midlands	2046	2147	+5	2220
11. East Pennines	2051	2169	+6	2204
14. East Scotland	2309	2449	+6	2509

Appendix 2: Classification of Microbiological Laboratories

The following classification of biological agents into Hazard Groups 1 to 4 are taken from the Advisory Committee on Dangerous Pathogens (ACDP) 'Approved List of biological agents' according to hazard and categories of containment'[9]:

Hazard Group 1 - unlikely to cause disease.

Hazard Group 2 – can cause disease and may be a hazard to employees, is unlikely to spread to the community and there is usually an effective prophylaxis or treatment available.

Hazard Group 3 – can cause severe human disease and may be a hazard to employees, it may spread to the community but there is usually an effective prophylaxis or treatment available.

Hazard Group 4 – causes severe human disease and is a serious hazard to employees, is likely to spread to the community and there is usually no effective prophylaxis or treatment available.

[8] Data from http://vesma.com/ddd/index.htm
[9] http://www.hse.gov.uk/pubns/misc208.pdf