Energy Consumption of University Laboratories: Detailed Results from S-Lab Audits

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S-Lab (Safe, Successful and Sustainable Laboratories) initiative of
HEEPI (Higher Education for Environmental Performance Improvement)
See www.goodcampus.org

Lab-CURE: Chemicals, Utilities, Resources and Environment in Laboratories

Contents

About HEEPI and S-Lab

The *Higher Education Environmental Performance Improvement* (HEEPI) project supports sustainable development, and especially environmental improvement, in universities and colleges through: identification and dissemination of best practice; creation and maintenance of networks; development of benchmarking; and in other ways. It is based at the University of Bradford.

S-Lab (Safe, Successful and Sustainable Laboratories) is one of its initiatives and aims to create more sustainable laboratories, without jeopardising – and in many cases enhancing – safety and performance.

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Malcolm Tait is a Partner at K J Tait Engineers, which carried out the audit at Cambridge.

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Disclaimer

Every effort has been made to ensure that the information in this document is accurate. However, it should not be used as a substitute for professional advice on detailed matters of laboratory design and management.

Summary

Laboratories consume large quantities of energy – often 3 to 4 times more than offices on a square metre basis. However, their complexity makes it difficult to develop a detailed understanding of how energy is used, and therefore to identify and prioritise improvement opportunities. To fill this knowledge gap, S-Lab has conducted, or collaborated with, detailed audits of energy use at three life science laboratories at the Universities of Edinburgh, Liverpool and York, and two chemistry laboratories at the Universities of Cambridge and Manchester. However, because the work has involved a number of assumptions, and because there is a high degree of variability in different labs even within the same discipline, and even within the same lab at different times, care is advised in interpreting the results, either to compare the audited laboratories or in applying them to others. The headline results from the exercise are:

- Ventilation-related energy (all the energy used to move, cool and heat air) comprises around 60% of total energy in chemistry labs and 45% in life science labs.
- Equipment/small power comprises around 25% in life science labs and 15% in chemistry labs.
- Space heating accounts for around 20% in both types of lab.
- Lighting comprised around 10% for life science labs and 5% for chemistry.
- Fume cupboard energy costs are £900-1500 per annum.
- The annual cost of moving a cubic metre of air through the labs each second ranged from £1,861-4,634, and that of a single air change per hour from £6,311-34,129.

The investigations also highlighted the importance of IT in many laboratories – in all cases as a significant element of equipment/small power category, and in some through self-contained server rooms (which are 17% of total consumption at Cambridge).

Detailed analysis at Liverpool and Manchester identified the most energy consuming equipment types (as a result of either numbers of equipment, power and hours of usage) which were:

- For chemistry, heaters / stirrers, mass spectrometers, rotary evaporators, gas chromatographs, nuclear magnetic resonance spectroscopes, ovens, fridges, pumps and water baths.
- For life science, freezers (-20 and -80) environmental growth chambers, water baths, incubators, ovens, ice makers, hybridisers, incubators and thermal cyclers.

The analysis did not include many large pieces of equipment with 3-phase power supply. While each lab will be different, a general rule of thumb is anything that is heating or cooling, is on 24/7, or has a 3-phase power supply, is likely to be a significant energy consumer.

The exercise demonstrated that developing a more detailed understanding of energy consumption can provide many benefits, including highlighting many opportunities for minimising energy consumption and saving money; improving safety; and building better relationships between Estates and laboratory staff. As subsequent reports will describe, the exercise suggests that there is the potential to reduce UK university energy bills by tens of millions of pounds through schemes that have a five year payback or less. A parallel guide to the audit process is also available.

1. Introduction

The S-Lab programme aims to create more sustainable laboratories, and to raise sustainability awareness amongst lab-using staff and students, without jeopardising – and in many cases enhancing – safety and performance. One aspect of its activities is the development of tools and guidance materials to assist laboratory energy efficiency initiatives. To assist this, and to provide reference data, the project conducted, or collaborated with existing, investigations of energy use at three life science and two chemistry facilities in UK universities in 2008-10. They were (in alphabetical order):

- The Department of Chemistry at the University of Cambridge;
- The Cancer Research Centre at the University of Edinburgh;
- The Biosciences Building (academic section only) at the University of Liverpool ;
- The Department of Chemistry (new extension only) at the University of Manchester; and
- The Department of Biology (Blocks K, L, and M only) at the University of York.

Appendices A-E provide detailed information on each of the laboratories, whose main features are summarised in Table 1.

Appendix F provides details of the main data sources that were used in the exercise. Developing the data took much more time than was envisaged at its start, and demonstrated that a considerable commitment is needed in order to build a reasonably accurate picture. However, the audits also demonstrated that this commitment is worthwhile, as they identified many opportunities for cost-effective measures to minimise energy consumption. The findings from this aspect of the exercise will be incorporated into a subsequent report.

A parallel report also incorporates the learning from the exercise into advice on the process of conducting audits and laboratory improvement.[1]

[1] Hopkinson, L., James, P., Lenegan, N., Somervell, D. and Tait, M., *Laboratory Energy Audits: S-Lab Process Guide* (2011). See www.goodcampus.org.

Table 1: Summary of Laboratory Features

	Date Built	Floor Area (sq.m)	Total Energy (kWh/y)	Total Electricity (kWh/y)	Total Gas (kWh/y)	Energy Use per Unit Area (kWh/sq.m/y)	Energy Cost per Unit Area (£/sq.m/y)	Ventilation-related as % of Total Energy	Equipment as % of Total Energy
Cambridge - Chemistry Building	1950's (major refurb 1990s)	27,603	19,537,914	10,251,111	9,286,803	707	40	51%	17%
Cambridge - Chemistry Building Excluding Server Room Energy		As above	17,698,506	8,411,703	As above	641	33	57%	19%
Edinburgh Cancer Research Centre	2002	3,000	2,937,408	1,268,111	1,669,297	979	67	38%	21%
Edinburgh - Cancer Research Centre Excluding Autoclave Energy		As above	2,421,480	As above	1,153,369	807	60	47%	26%
Liverpool – Biosciences Building (Academic Section)	2003	7,750	5,237,743	3,092,930	2,144,814	676	40	43%	23%
Manchester - Chemistry Building (Extension)	2006	3,816	2,488,242	883,407	1,604,835	652	28	61%	12%
York - Department of Biology (Blocks K, L & M)	2002	12,740	8,660,308	5,024,386	3,635,922	679	36	45%	22%

2. The Importance of Laboratory Energy

Laboratories consume large quantities of energy (and other resources); often more than three or four times the rate for offices on a square metre basis. The energy costs for a typical 5,000 sq.m bioscience laboratory are around £193,000 a year, compared to around £50,000 for a typical office of the same size.[2] There are a number of laboratories in the sector which have energy bills approaching over £1 million per year. Results from previous rounds of HEEPI benchmarking showed that not only were laboratories some of the most energy intensive buildings on a campus, but also that the energy intensity (kWh/sq.m/year) was increasing rather than decreasing over time.[3]

This energy intensity means that the energy and carbon-related emissions from laboratory-related activities can be between 50-80% of total non-residential emissions at science- and technology-intensive universities. It is therefore impossible for them to meet the carbon targets being set in the UK without doing more to minimise laboratory energy consumption, and other carbon impacts. However, this is difficult, with one barrier being limited information on how the energy in laboratories is used, making it difficult to identify opportunities for improvement. Data available from US laboratories suggests that ventilation is a key issue, particularly for chemistry laboratories,[4] and it has always been suspected that this is the case in the UK also. However, until this exercise it was hard to know for sure.

The S-Lab energy audits were therefore carried out to address the gaps in current knowledge and provide a detailed breakdown of energy use in UK university laboratories by different categories, and to identify the main improvement opportunities. They have taken 8-10 person months of work in total, and therefore represent some of the most robust studies on the topic which have been conducted, in the UK or elsewhere.

3. Audit Details

The work began in 2008 and was mainly conducted in 2009/2010. Two of the investigations, at Liverpool and Manchester, were carried out directly for S-Lab by Nigel Lenegan, of Energy & Carbon Reduction Solutions, using basic metered data supplied by the universities. Nigel also led the York investigation, in collaboration with the then Department of Biology Energy Manager, Jo Hossell (now in the Estates Department), using detailed information developed by her.

The Edinburgh investigation was carried out by Tom McGrath, a mature engineering student at the university, supervised by the Sustainability Manager, David Somervell. The Cambridge investigation was carried out by Malcolm Tait of K J Tait Engineers directly for the university, and the results have been used with permission, and with slight adjustment to conform to the S-Lab categories.

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[2] Using the typical HEEPI lab benchmarks and Carbon Trust office benchmarks shown in Table 3 and assuming 10p/kWh for electricity and 3p/kWh for gas.

[3] Hopkinson L. and James P., *Sustainable Laboratories for Universities and Colleges – Reducing Energy and Environmental Impacts* (2007). Available at www.goodcampus.org. See Tables 3 & 5 in this report for the benchmark figures for life science and chemistry laboratories respectively.

[4] See www.labs21century.gov/toolkit/benchmarking.htm.

Table 2 summarises the general categories that were used, and how they were derived. Achieving this categorisation was not straightforward. Some aspects had to be allocated between different activities, e.g. gas heating between HVAC-related and general space heating. In some cases activities were so large that metered data was available on them – for example, server room consumption at Cambridge – but this was not possible in many cases.

Electricity consumption associated with personal computing (desktop and laptop computers, printers etc.) is grouped in the 'Equipment and Small Power' category, as these are generally metered together with lab equipment. For the same reason electricity from split DX air conditioning units was also grouped under 'Equipment and Small Power' rather than the 'Cooling' category; the latter refers to central chillers and related pumps only. Electricity consumption associated with central services (e.g. compressed air and nitrogen) which was separately metered at some labs, was also included under the 'Equipment and Small Power' category.

Because of the important contribution of ventilation in laboratories, a 'Ventilation-related' category was estimated, which comprised all the energy used to move, cool and heat air. This required a proportion of natural gas heating energy to be allocated to ventilation (as opposed to direct space heating), i.e. a lab-space where heated air is exhausted through the ventilation system will require more heating energy than a space without mechanical ventilation. This was done by assuming that space heating was equivalent to the figure for a naturally ventilated office (151 kWh/sq.m/year) given in a Carbon Trust report[5], and that the remaining heating load - which was generally around 60-65% of the total - was related to the laboratory mechanical ventilation system.

Electricity consumed by heating pumps and chillers was also included in the 'Ventilation-related' category.

Appendix F provides further details of how the S-Lab estimates were derived at the individual laboratories.

[5] Carbon Trust, Energy Use in Government Laboratories (ECG083), London, 2002, page 5-2. Downloadable from: http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=ECG083.

Table 2: Categorisation of Energy Consumption in Laboratories

Energy Categories	**Electricity-related Activities**	**Gas-related Activities**
Ventilation-related	General supply General extract Fume cupboard extract Special area ventilation Electrical heating re ventilation (pumps) Electrical cooling re ventilation (chillers, pumps)	Boilers (Total energy minus space heating energy – see below)
Space Heating (conventional space and water heating)	Electrical heaters – not present in any of the labs audited	Boilers (based on Carbon Trust benchmark figure per sq.m)
Equipment and Small Power	Scientific equipment, IT equipment other than servers, split DX air conditioning units etc. Central services – gases, compressed air etc.	
Lighting	All lighting	
Server Rooms	All power supplied to server rooms including servers, UPS, cooling where significant load (Cambridge)	

4. Summary Results – Life Science

The three life science laboratories are very different in terms of size, layout and the science conducted within them. The Edinburgh Cancer Research Centre is a specialised research facility; the York laboratories audited are research-only whereas Liverpool is a mixed teaching and research facility. All three labs operate 24/7 although Edinburgh is unusual in that its main ventilation system only operates during the daytime (there are designated fume cupboards and areas for activities requiring 24/7 services). Edinburgh has a large onsite autoclave served by a steam-boiler for sterilising biological waste and glassware, York has a steam autoclave serving a small part of the facility, while Liverpool did not have an autoclave within the area audited. To aid direct comparison the analysis for Edinburgh includes data both with and without the autoclave energy included.

The breakdown of total energy consumption at Liverpool, Edinburgh and York are shown in Figures 1-4 below. It is evident that ventilation-related energy (which includes cooling and heating related to ventilation) is – if the unusually high autoclave consumption at Edinburgh is discounted - within a range of 43-47%. Equipment/small power accounts for between 22-26% of total energy while space heating is between 19-23% of total energy.

Figures 5-8 below show the analogous results for energy costs. If the Edinburgh autoclave consumption is excluded, ventilation-related costs are 38-44% of total energy costs, while there is a much wider variation in small power/equipment, between 30-42%. Possible explanations for this range are different types of science being carried out in the three labs, and the way that the data was collected. The figures at Liverpool and York were based on sub-metered data pro-rated by floor area, whereas at Edinburgh it was a bottom-up estimate (see Appendix F for more details on sources of information).

Figure 1: Liverpool Total Energy Consumption

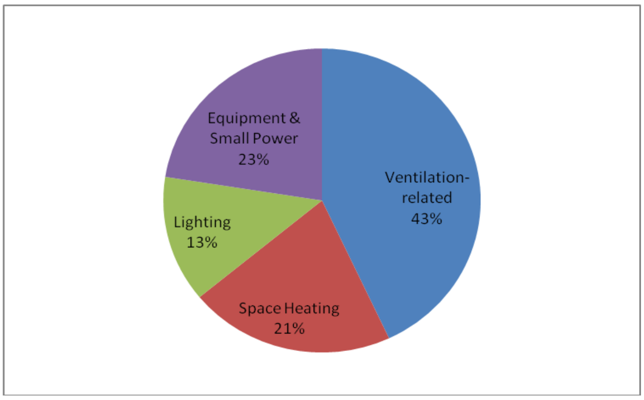
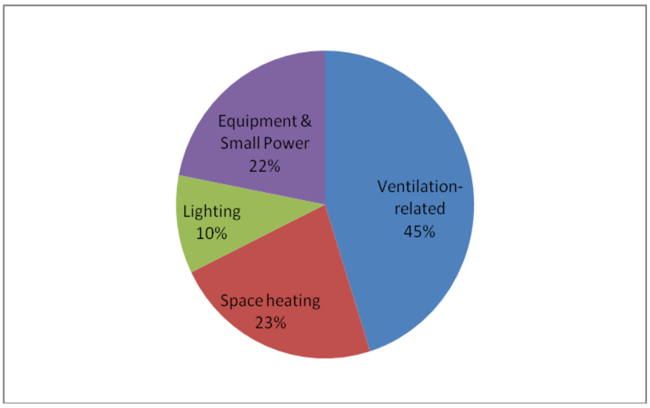
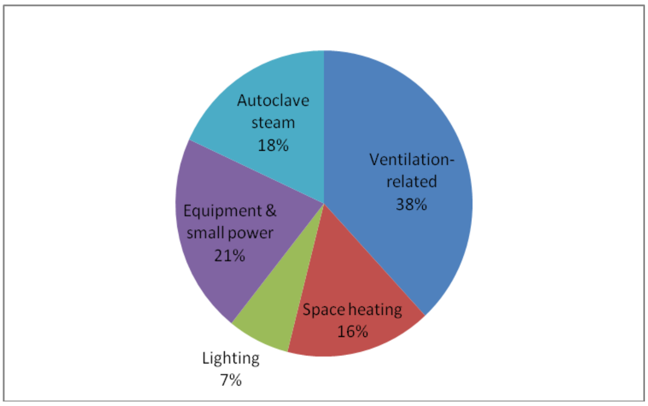


Figure 2: York Total Energy Consumption



Figures 3 & 4: Edinburgh Total Energy Consumption With and Without Steam Autoclave



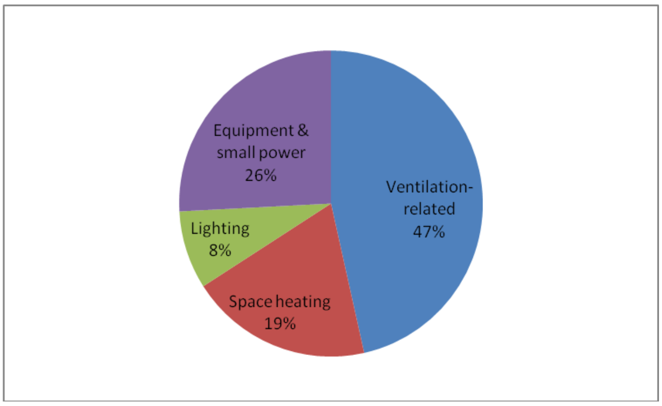


Figure 5: Liverpool Total Energy Costs

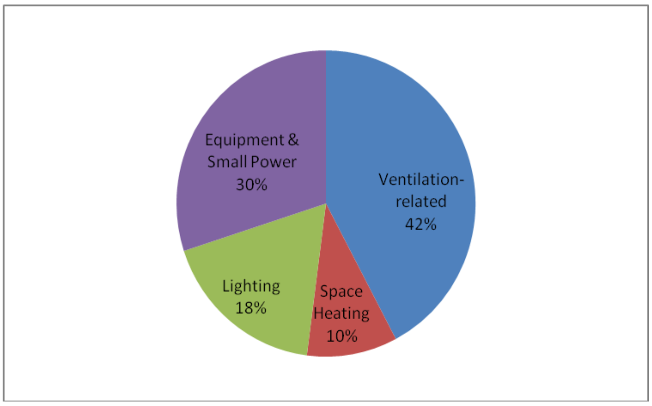
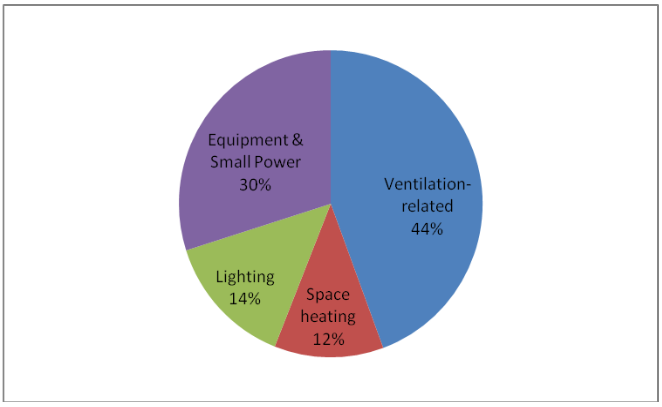
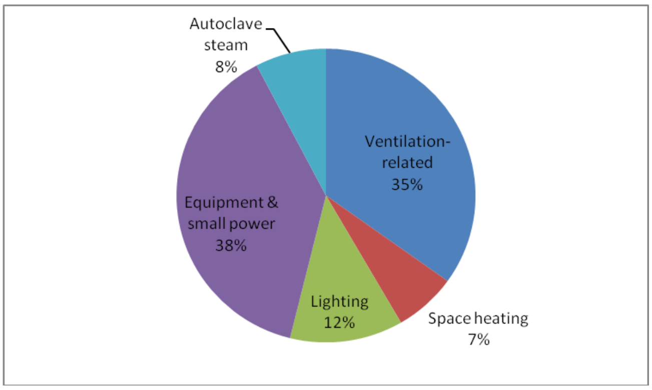


Figure 6: York Total Energy Costs



Figures 7 & 8: Edinburgh Total Energy Costs With and Without the Steam Autoclave



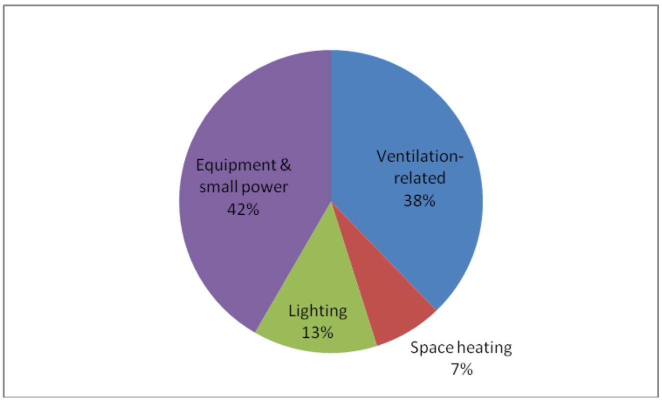


Table 3 below shows that all three labs had higher energy, and especially electricity, consumption than the HEEPI 2007 typical benchmark. Some possible explanations may be that all three are intensively used compared to the norm, and/or that the HEEPI benchmarks are under-estimates, perhaps because equipment intensity is increasing with time. The Edinburgh result seems surprisingly high but there are a number of possible explanations:

- The types of research carried out could be more energy intensive at Edinburgh (though the electricity benchmark is similar to York, also purely research);
- Edinburgh is a much more northerly location accounting for higher gas consumption;
- Edinburgh has inefficiencies in certain areas (e.g. autoclave); and

- Liverpool and York could be slightly underestimated as the overall energy data was not based on direct metering (though the data has been thoroughly checked and the divergence is unlikely to be high).

Table 4 shows very rough estimates of the annual cost per hourly air change and cubic metre of air movement and conditioning in the life science facilities. These figures have an even stronger 'health warning' than others in the report because they involve very crude assumptions about building volumes, and exclude any special ventilation. They are nonetheless of interest because they show the cost savings that can be achieved by relatively small changes in the amount of air moved, or hourly air change rates.

Table 3: Energy Comparisons for the Three Life Science Laboratories (kWh/sq.m/year)

	Typical Office Benchmark[6]	HEEPI Lab Benchmark[7]	Edinburgh	Edinburgh Excluding Autoclave	Liverpool	York
Total Electricity	54	300	392	392	399	394
Total Gas	151	289	556	384	168	285
Total Energy	205	589	979	807	676	679
Ventilation-related	6	Not estimated	361	361	310	301
Equipment and Small Power	22	Not estimated	200	200	162	117

Table 4: Annual Cost per Hourly Air Change and Cubic Metre of Air Movement and Conditioning

	Cambridge	Edinburgh	Liverpool	Manchester	York
Total HVAC Energy Cost (£)	500,507	66,007	141,501	69,050	200,291
Design Air Supply (m^3/s)	108	20	42	37	66
Estimated Hourly Air Change	NA due to building complexity	7.5	6.1	10.9	5.9
Annual Cost of Air Movement (£/m^3/s)	4,634	3,294	3,369	1,861	3,013
Annual Cost per Hourly Air Change (£)	NA due to building complexity	8,783	23,209	6,311	34,129

[6] Benchmarks for a typical naturally ventilated cellular office, from Carbon Trust, Energy use in offices (ECG019) (2003) available at: www.carbontrust.co.uk

[7] See footnote 2. The figures are 2007 benchmarks for a typical medical/bioscience lab without secure facility.

5. Summary Results - Chemistry

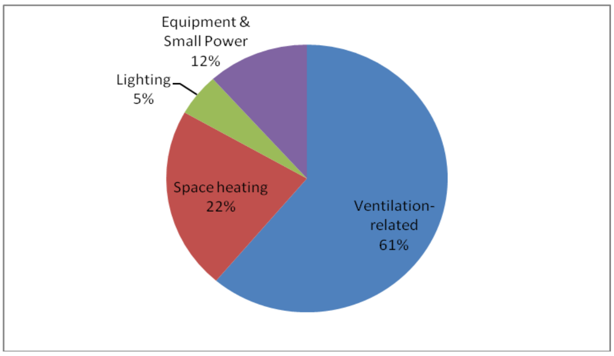
The two chemistry laboratories are also very different in scale and activities, and there are some difficulties in comparing them. At Cambridge the whole chemistry building was assessed. At Manchester only the extension of the main chemistry building was assessed which included two teaching and a number of research labs. Cambridge also has a very high server component, which Manchester does not (as the servers are located elsewhere). To aid direct comparison the analysis includes the Cambridge data with the server room energy excluded. The breakdowns in terms of total energy are shown overleaf.

Figures 9-11 show that the breakdowns are very similar for the ventilation-related (51-61%) and space heating (18-22%) categories – though the latter may be a result of using the same benchmark figure for space heating. Cambridge consumes a higher proportion of energy on Equipment and Small Power (17-19%, than Manchester (10-12%). Note that the Cambridge equipment energy estimate is subject to higher uncertainty because it is a residual figure.

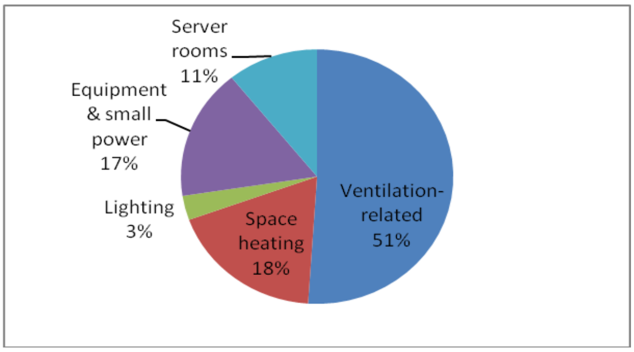
Figures 12-14 show that there is a similar breakdown for energy costs (if the Cambridge server rooms are excluded), with ventilation-related costs being 57-61% and equipment and small power 21-31% .

Table 4 above provides figures on the cost of hourly air changes and air movement within the two laboratories.

Figure 9: Manchester Chemistry Total Energy Breakdown



Figures 10 and 11: Cambridge Chemistry Total Energy Breakdown With and Without Server Consumption



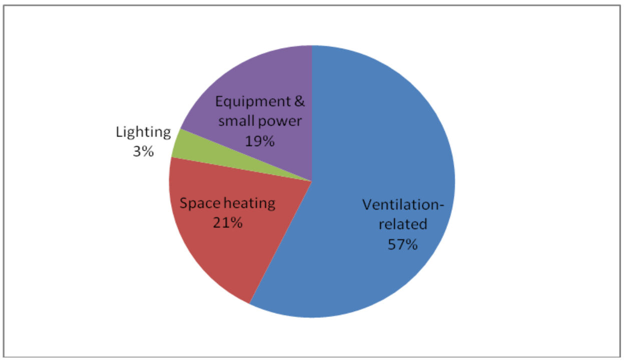
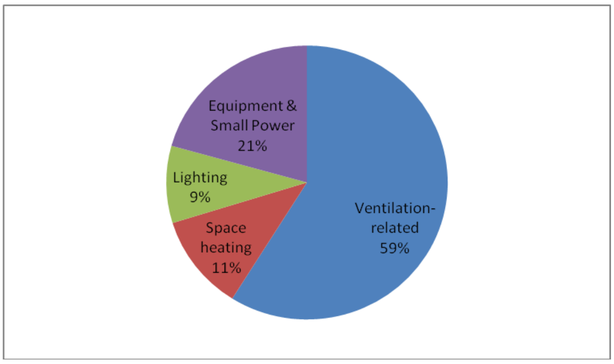
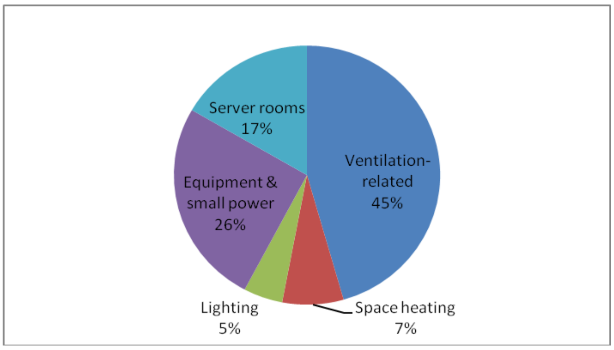


Figure 12: Manchester Chemistry Total Energy Costs (Central Services energy included in Equipment & Small Power category)



Figures 13 and 14: Cambridge Chemistry Total Energy Costs With and Without Server Consumption



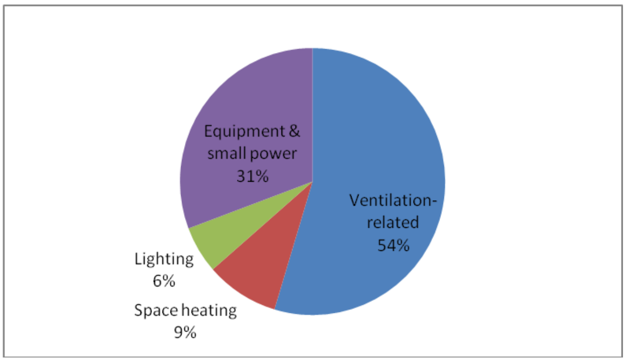


Table 5 shows that total energy and electricity consumption at both Manchester and Cambridge (excluding servers) is below the HEEPI 2007 benchmark figures for a typical chemistry laboratory. Gas consumption at Manchester is higher and at Cambridge lower than the benchmark figure. These findings may reflect the fact that, unusually, the Manchester laboratory is not cooled in summer, and the fact that both – and especially Cambridge – have devoted considerable effort to reducing energy use.

Table 5: Energy Comparisons for the Two Chemistry Laboratories (kWh/sq.m/year)

	Typical Office Benchmark [8]	HEEPI Lab Benchmark [9]	Cambridge	Cambridge excluding servers	Manchester
Total Electricity	54	367	371	295	232
Total Gas	151	353	336	336	421
Total Energy	205	720	708	631	652
Ventilation-related	6	Not estimated	361	361	419
Equipment and Small Power	22	Not estimated	117	117	58

[8] Carbon Trust, see footnote 4.
[9] See footnote 2. The figures are 2007 benchmarks for a typical chemistry laboratory.

The data generated by the audits was used to estimate the annual energy consumption and energy costs of fume cupboards in the two laboratories. The figures produced are £1,277 for Cambridge and £891 for Manchester. Both of these are approximate, and there are also significant differences between the laboratories, especially the absence of cooling at Manchester and closure of some of its plant during the period of the survey.

Hence, no conclusions about the relative efficiency of each can be drawn from the figures. Their main significance is to validate the often made statements that fume cupboards are expensive to operate, and to provide a ballpark figure of £900-1,500 for their actual energy costs in practice. (An upper figure of £1,500 is reasonable given that Cambridge has some efficiency features that are not present in many labs, and that some older fume cupboards are known to be even more expensive).This range is lower than figures that are sometimes quoted, which probably reflects improvements in energy efficiency in the decade since previous detailed work was done.

6. Equipment Energy

Detailed, bottom up analyses of equipment energy were undertaken at the Liverpool Biosciences facility, the Manchester Chemistry extension and, less thoroughly, the Edinburgh Cancer Research Building (see Tables C4, D5 and B4 in the respective Appendices). The estimates were based on numbers of equipment, rated power (where available) and estimated usage of equipment. Reduction factors were applied to the rated power to account for the fact that average power in use is usually much lower than the rated peak power.

The analyses were not comprehensive as they generally excluded bespoke or 3-phase equipment, where it was difficult to estimate power consumption. While there are many inherent difficulties in estimates of this nature, they do provide some ballpark figures on equipment energy use. Table 6 summarises the top 10 equipment types (in descending order) in the two laboratories.[10]

Table 6: Significant Energy Consuming Equipment in Chemistry and Life Science Laboratories (in descending order with most significant at the top of the list)

Chemistry	**Life Science**
Heaters/Stirrers	Freezer (-20)
Mass Spectrometry	Environmental Chamber
Gas Chromatography	Water bath
Rotary Evaporators	Incubator
NMR	Freezer (-80)
Ovens (Chemical)	Oven
Fridges	Ice maker
Diaphragm Pumps	Hybridiser
Vacuum Pumps	Incubator-shaker
Water Baths (Large)	Thermal Cycler (PCR)

[10] For more discussion of equipment energy and other environmental impacts see Hopkinson L. and James P., 2011, Saving Money Through Sustainable Procurement of Laboratory Equipment. Available at www.goodcampus.org.

7. Conclusions

Our investigations have highlighted the high energy consumption and costs of laboratories, and the fact that ventilation (and associated cooling and heating) is the most important component of this. Table 7 summarises a 'rule of thumb' split of laboratory energy consumption, and shows that ventilation accounts for around 60% in chemistry and 45% in life science. It also provides the energy split for an office – where the main elements are space heating, hot water and lighting - and thereby demonstrates how much they differ from laboratories.

The investigations have also highlighted the importance of IT in many laboratories. Where they exist, server rooms can be a significant and growing component of consumption – accounting for 17% of total consumption at Cambridge.

Undertaking this exercise has demonstrated that, despite the difficulties, it is worthwhile for many reasons, including:

- Highlighting, and providing information to support a business case for, many opportunities for minimise energy consumption and saving money, by tackling ventilation systems. Some of these have already been adopted in one or two of the laboratories but all would admit that there is scope for more.
- Assisting research and teaching, for example, by identifying poorly performing equipment and systems.
- Gaining a better knowledge of equipment numbers and usage which can enable improved procurement, and more sharing of equipment between laboratories.
- Enhancing safety through a more thorough understanding of both laboratory activities and the detailed workings of ventilation systems, as well as their interaction.
- Improving cross-functional working relationships, especially between Estates and laboratory staff.

As a subsequent report will describe, the exercise suggests that there is the potential to reduce UK university energy bills by tens of millions of pounds through schemes that have a five year payback or less.

Table 7: Broad Estimates of Energy in Typical Laboratories by Category

Category	**Approximate Percentage of Total Energy**		
	Life Science Laboratory	Chemistry Laboratory	Typical Office[11]
Ventilation-related	45%	60%	3%
Space/water heating	20%	20%	74%
Equipment and small power	25%	15%	12%
Lighting	10%	5%	11%

[11] Carbon Trust benchmark for typical naturally ventilated cellular office, see footnote 4.

Appendix A - Energy Consumption in the University of Cambridge's Chemistry Building

S-Lab would like to acknowledge the use of data and other information supplied by Malcolm Tait of K J Tait Engineers who completed an energy audit of the University of Cambridge's Department of Chemistry building in 2009/2010. S-Lab has re-categorised some of the data to allow comparison with the other lab audits, but the main data collection has been conducted by K J Tait Engineers.

The Chemistry Building is a 3-storey building of 27,600 sq.m which is used for both teaching and research. It was constructed in the 1950s and had undergone continual refurbishments since then, including a major re-fit of the roof plant in the mid 1990s. There is only a mains gas and a mains power meter serving the building, therefore the electricity consumption by category has been estimated in various ways.

The building has 328 constant volume fume cupboards. Heating is provided by four natural gas fired boilers, while there are also four electrically powered steam boilers. Six chiller units provide cooling to the whole building with additional cooling for scientific equipment provided by over 200 split DX units. The building has a large IT component with 10 energy-intensive server rooms housing High Performance Computing.

A1. Overview

Table A1 provides data on the metered electricity and gas for the building for the academic year 2007/08. It shows that the Chemistry Building:

- Consumed over 19 million kWh of energy comprising 10 million kWh of electricity and 9 million kWh of gas.
- Had an annual energy cost of over £1 million in total, comprising around £890,000 in electricity (at 8.7p/kWh) and £211,000 in gas (at 2.3p/kWh).

Table A2 and Figures A1 and A2 give a breakdown of total electricity consumption, with and without server energy. This allows comparison with other chemistry buildings without server rooms. Figure A1 shows that ventilation and lab equipment/small power comprise an estimated 32% each with the server rooms a further 20% of electricity consumption. Figure A2, which excludes server energy, shows ventilation and lab equipment/small power comprise the majority (80%) of electricity consumption in the building.

Table A3 and Figure A3 give a breakdown of total energy in the building. Figure A3 shows that heating (gas consumption plus electrical heating) comprises nearly half of total energy consumption.

Figures A4 and A5 show the breakdown of total energy (including and excluding server rooms respectively) after a portion of the gas heating energy is reassigned to the ventilation category. When server rooms are included (Figure A4) approximately half (51%) of the energy consumption of the building is ventilation-related, associated with moving and conditioning (heating, cooling) air. A further 18% is space heating and an estimated 17% is equipment and small power. When server rooms are excluded (Figure A5), approximately 57% of energy consumption is ventilation-related, 21% is space heating and 19% is equipment and small power.

Lastly, Figures A6 and A7 show the breakdown of total energy costs. When server room energy is included, ventilation-related emissions are 45%, equipment/small power 26% and server rooms 17% of total energy costs. When server room energy is excluded, ventilation-related emissions are 54% and equipment/small power 31% of total energy costs.

Table A1: Details of Energy Consumption and Costs of the Chemistry Building, University of Cambridge

	Gross Internal Area (sq.m)	Electricity (kWh/y)	Electricity Cost (£/y)	Gas/heat (kWh/y)	Gas/heat Cost (£/y)	Total Energy (kWh/y)	Total Energy Cost (£/y)
Chemistry Building	27,603	10,251,111 (metered)	887,746	9,286,803 (metered)	210,810	19,537,914	1,098,556
Annual Energy Consumption per Unit Area (kWh/sq.m/y)		371		336		707	
HEEPI Typical Benchmark for Chemistry (kWh/sq.m/y)		367		353		720	
Annual Energy Cost per Unit Area (£/sq.m/y)			32		8		40

Table A2: Estimated Electricity Consumption and Cost in the Chemistry Building, University of Cambridge

Category	**Sub-category**	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Ventilation	General Supply	1,577,341	136,598	Estimate based on running hours and nameplate motor rating.
	General Extract	98,280	8,511	As above.
	Fume Extract	1,597,727	138,363	As above.
	Sub-total	3,273,348	283,472	Sum of ventilation sub-categories.
Heating Pumps		373,318	32,329	Estimate based on running hours and nameplate motor rating.
Cooling (chillers & pumps)		642,213	55,616	Chillers only. Does not include split DX units.
HVAC Total		4,288,879	371,417	Ventilation plus heating plus cooling above.
Lighting		604,800	52,376	Assumed lighting benchmark of 64 kWh/sq.m.
Equipment and Small Power		3,248,024	281,279	Residual of metered electricity minus other categories. Small power includes split DX units and general IT equipment (PCs, monitors, imaging equipment and equipment IT).
IT (Server Rooms)		2,109,408	182,675	Server energy and server cooling only. General IT included in small power.
Total Electricity Consumption from Metered Data		10,251,111	887,746	See Table A1.

Table A3: Estimated Energy Consumption and Costs in the Chemistry Building, University of Cambridge

Category	Consumption (kWh/y)	Cost (£/y)	Basis of Estimate
Electricity – Total	10,251,111	£887,746	See Table A1, metered data.
Electricity – HVAC	4,288,879	£371,417	See Table A2. Note this does not include split DX units.
Electricity – Other	5,962,232	£516,329	See Table A2 – residual from HVAC.
Gas Consumption Total	9,286,803	£210,810	See Table A1.
Heating (Gas) – Space	3,600,000	£81,720	Based on metered data for heating and hot water. In other S-Lab audits this data was not available therefore assumed space heating as a naturally ventilated office = 151 kWh/sq.m /year (from ECG83 - see reference in Section 3). This gives a figure of 4,168,053 kWh which is 16% higher than the metered data.
Heating (Gas) - Ventilation	5,686,803	£129,090	Total gas consumption minus space heating component.
HVAC Energy	9,975,682	£500,507	Electricity – HVAC plus Ventilation Heating element of Gas.

Table A4: Estimated Fume Cupboard Energy and Costs in the Chemistry Building, University of Cambridge

Element	Consumption (kWh/y)	Cost (£/y)	Basis of Estimate
Fume Extract Fans	1,597,727	£138,363	Figure from Table A2.
Supply AHU's – Fans	1,498,474	£129,768	95% of total fan energy – based on an informed engineering estimate that only 5% of supply air is removed via general extract fans.
General Extract Fans	98,280	£8,511	Figure from Table A2.
Heating Pumps	227,724	£19,721	61% of the total heating pump power 373,318 kWh given in Table A2, i.e. it was assumed that 39% of the load was related to space heating, as per Table A3 and Section 3.
Fresh Air - Heat Only (no cooling or (de)humidification)	5,402,463	£122,635	95% of the natural gas heating associated with ventilation (5,686,803 kWh - see Table A3).
Total Fume Cupboards	8,824,668	£418,998	Sum of all the above.
Per Fume Cupboard	26,904	£1,277	For 328 fume cupboards at 0.5 m/s face velocity.

Figure A1: Breakdown of Estimated Electricity Usage, Chemistry Building, University of Cambridge

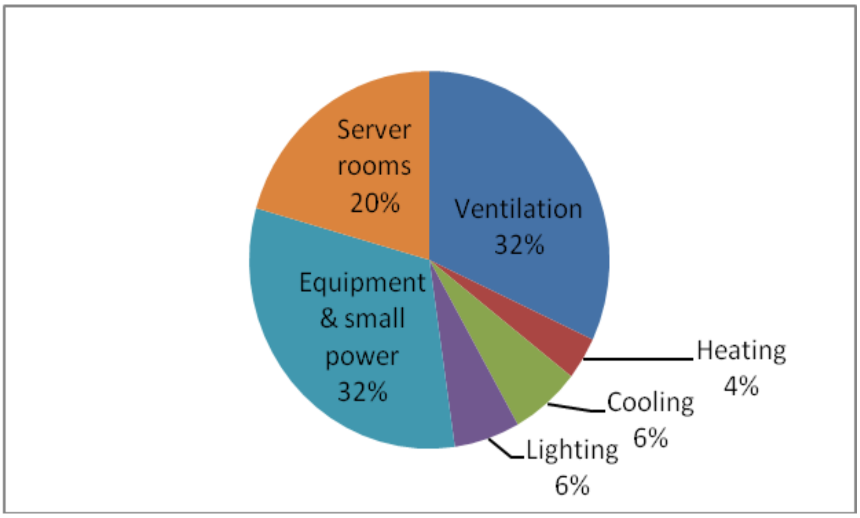


Figure A2: Breakdown of Estimated Electricity Usage Excluding Server Rooms, Chemistry Building, University of Cambridge

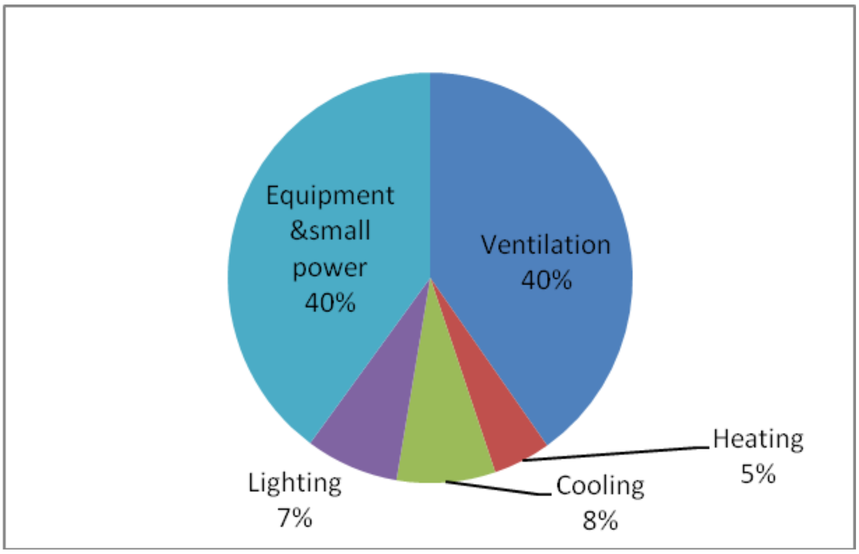


Figure A3: Breakdown of Estimated Total Energy Usage, Chemistry Building, University of Cambridge

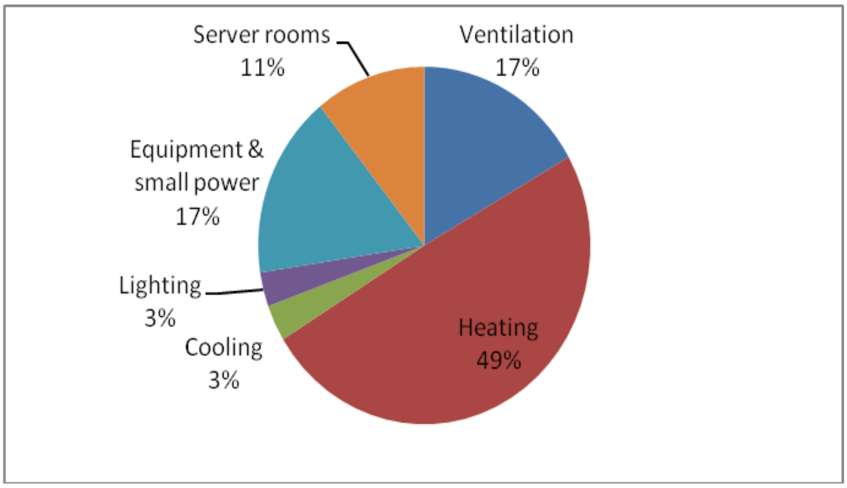


Figure A4: Breakdown of Estimated Total Energy Usage (Server Rooms Included), Chemistry Building, University of Cambridge (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

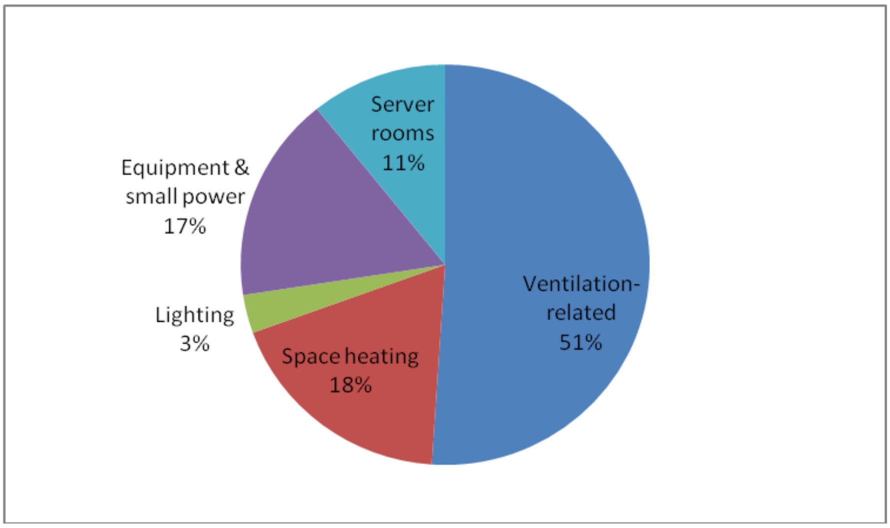


Figure A5: Breakdown of Estimated Total Energy Usage (ServerRooms Excluded), Chemistry Building, University of Cambridge (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

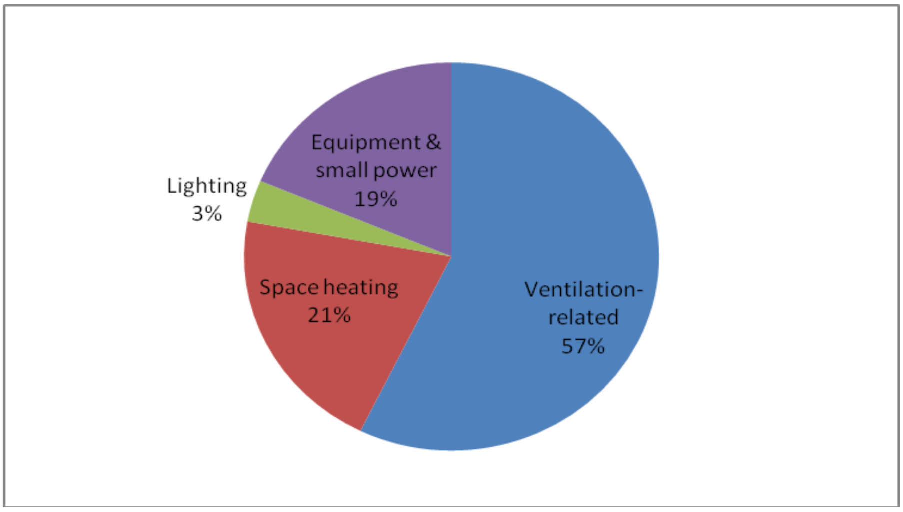


Figure A6: Breakdown of the Estimated Costs Associated with Total Energy Usage (Server Rooms Included), Chemistry Building, University of Cambridge (With Heating Component of Ventilation Included in Ventilation-Related Category

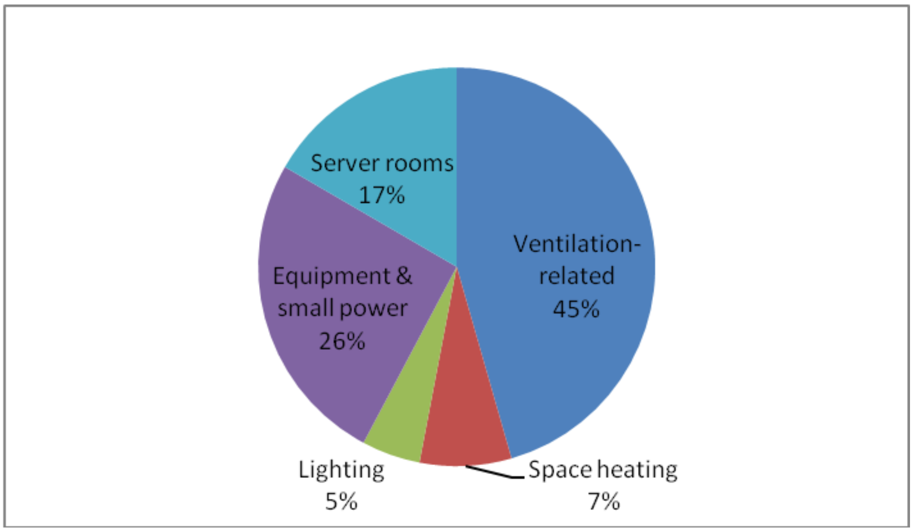
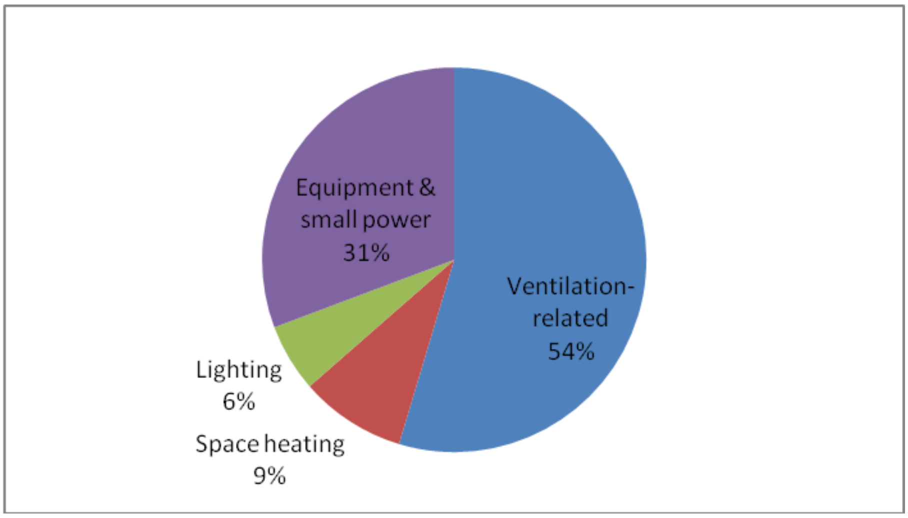


Figure A7: Breakdown of the Estimated Costs Associated with Total Energy Usage (Server Rooms Excluded), Chemistry Building, University of Cambridge (With Heating Component of Ventilation Included in Ventilation-Related Category



Appendix B - Energy Consumption in the University of Edinburgh's Cancer Research Centre

The University of Edinburgh Cancer Research Centre is a five-storey standalone building of 3,000m² completed in 2002 at a capital cost of £7 million. It is primarily a biomedical research laboratory that houses approximately 130 full-time staff and is one of a number of Cancer Research UK funded laboratories across the UK.

The Centre operates a night-time setback reducing the running costs associated with continuous HVAC operation. This setback was conceived from the very outset to contain energy costs and has been achieved through education of staff in good practice in energy management. A typical HVAC operating day is from 5 a.m. to 10 p.m. with further reduced hours at weekend (and as a result of this study "occupancy" hours will be reviewed to further cut down HVAC costs). The building maintains access to staff on a 24/7 basis with the option of using the microbiological safety cabinets.

Monitoring is provided by separate meters for gas and electricity, electricity readings are taken every half hour, but there is no other sub metering. Heating is provided by three natural gas fired boilers (425kW) and a separate gas fired steam generator provides steam for the two onsite autoclaves. Two indoor, air cooled, chiller units (each with 328.5kW chilling capacity) provide cooling to the whole building. There are also a number of split DX units in specialist equipment rooms, including a dedicated -80 freezer room on the ground floor.

B1. Overview

Table B1 provides data for the size and estimated energy consumption of the building (based on pro rata figures for consistency). It shows that in the academic year 2009/10 it:

- Consumed nearly 3 million kWh of energy, comprising around 1.3 million kWh of electricity and around 1.7 million kWh of fossil fuel energy.
- Had annual energy costs of around £200,000, comprised of around £152,000 for electricity (at 12 p/kWh) and £48,000 for gas (at 2.8 p/kWh).

Table B2 and Figure B1 give a further breakdown of estimated electricity consumption. This shows that equipment and small power accounts for 51%, ventilation 16% and lighting 16% of total electricity.

Table B3, and Figures B2 and B3, provide a breakdown of total energy. Figure B2 shows that autoclave steam accounts for 18% and heating (gas and electric) 41% of total energy. Figure B3 shows the breakdown when the estimated autoclave component is excluded. This indicates that approximately 50% of the energy consumption of the building is associated with heating and 26% with small power.

Figure B4 shows the estimated total energy when the gas heating component of ventilation is grouped with ventilation-related electricity (ventilation, electrical heating and cooling), and autoclave energy is excluded. This shows that ventilation-related energy is responsible for 38% of the total energy.

Figures B5 and B6 show energy costs, with autoclave energy excluded in the latter. Figure B6 shows that 42% of total costs are associated with equipment and small power, and 38% with ventilation.

Table B4 shows the estimated electricity consumption of scientific equipment (note that only the main energy-intensive items of equipment were included in the estimate). This is based on bottom-up estimates of energy using rated power (adjusted in many cases), estimated usage and numbers of equipment. This shows that general equipment is 48%, refrigeration equipment 34% (of which -80 freezers were the main component) and IT 18% of total equipment energy.

Table B1: Details of Energy Consumption and Costs of the Cancer Research Centre, University of Edinburgh

	Gross Internal Area (sq.m)	**Electricity (kWh/y)**	**Electricity Cost (£/y)**	**Gas/heat (kWh/y)**	**Gas/heat Cost (£/y)**	**Total Energy (kWh/y)**	**Total Energy Cost (£/y)**
Cancer Research Centre	3,000	1,268,111 (metered)	152,173	949,279 (a) 1,669,297 (b) (both metered)	26,580 (a) 48,036 (b)	2,421,480 (a) 2,937,408 (b)	178,753 (a) 200,209 (b)
Annual Energy Consumption per Unit Area (kWh/sq.m/y)		422		316 (a) 556(b)		738 (a) 979(b)	
HEEPI Energy Benchmark for Life Sciences (Excluding Secure Facility) (kWh/sq.m/y)		Good: 242 Typical: 300		Good: 196 Typical: 289		Good: 438 Typical: 589	
Annual Energy Cost per Unit Area (kWh/sq.m/y)			51		9(a) 16(b)		60(a) 67(b)

(a) excluding autoclave energy consumption

(b) including autoclave energy consumption

Table B2: Estimated Electricity Consumption and Costs in the Cancer Research Centre, University of Edinburgh

Category	**Sub-category**	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Ventilation	General Supply	123,068		Estimate based on running hours and nameplate motor rating. Reduced by 40% to take account of difference between rated and actual power consumption.
	General Extract	35,095		As above.
	Fume Extract	2,024		As above.
	Special Area	83,541		As above.
	Sub-total	185,653	22,278	Sum of ventilation sub-categories.
Heating Pumps		7,095	851	Estimate based on running hours and nameplate motor.
Cooling (chillers and pumps)		189,364	22,724	
HVAC Total		382,112	45,853	
Lighting		192,000	23,040	Assumed lighting benchmark of 64 kWh/sq.m.
Equipment and small power		601,211	72,145	Bottom up estimates based on rated power and estimated running time with some reductions applied. Small power includes split DX units.
Total Electricity Consumption from Bottom-up Calculations		1,175,323	141,039	Sum of HVAC plus central services, lighting and small power.
Total Electricity Consumption from Metered Data		1,268,111	152,173	See Table B1. Estimate is 7% less than metered data.

Table B3: Estimated Energy Consumption and Costs in the Cancer Research Building, University of Edinburgh

Category	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Electricity – Total	1,175,323	141,039	See Table B2 based on bottom up estimates.
Electricity – HVAC	382,112	45,853	See Table B2 –kWh of ventilation + ventilation-related electrical heating and cooling.
Electricity – Other	793,211	95,186	See Table B2 – residual from HVAC.
Gas Consumption Total	1,669,297	48,036	See Table B1.
Gas for Steam Boiler Serving Autoclave	515,928	14,846	Estimate from monthly gas consumption for summer months, assume 42,994 kWh/month.
Gas consumption for heating	1,153,369	33,189	Gas consumption total minus autoclave gas.
Heating (Gas) – Space	453,000	13,036	No data available, therefore, assume space heating as a naturally ventilated office = 151 kWh/sq.m/year (Carbon Trust, see footnote 4).
Heating (Gas)- Ventilation	700,369	20,154	Total heating minus space component.
HVAC Energy	1,082,481	66,007	Electricity - HVAC plus Heating -Ventilation element.

Table B4: Estimated Annual Electricity Consumption of Scientific Equipment based on Bottom-up Estimates, University of Edinburgh

	Total Use in kWh/y and (%)	Equipment List	Average Power (W)	Typical Usage (hrs/y)	Qty	Estimated Unit Energy Use (kWh/y)	Estimated Total Energy Use (kWh/y)	Estimated Total Costs (£/y)	% of Equipment List Total
Departmental Equipment	235,044 (48%)	Incubator	313		32	2,738	87,631	10,516	37
		Other Deptl Equip	184		51	1,609	82,084	9,850	35
		Water bath	289		8	2,528	20,224	2,427	9
		Centrifuge	128		18	1,118	20,127	2,415	9
		Oven	302		4	2,649	10,596	1,272	5
		Fume Cupboards	50		16	436	6973	837	3
		Shaker	96		8	841	6,726	807	3
		Hot Plates	26		3	228	683	82	0
Refrigeration	172,123 (34%)	-80 Freezer	1,200	8,760	12	10,512	126,144	15,137	73
		Under Bench Fridge	50	8,760	35	440	15,417	1,850	9
		Under Bench Freezer	50	8,760	30	438	13,140	1,577	8
		Tall Fridge	65	8,760	13	571	7,419	890	4
		Tall Freezer	28	8,760	19	245	4,660	559	3
		Ice Machines	200	8,760	2	1,752	3,504	420	2
		Tall Fridge/Freezer	80	8,760	2	701	1,401	168	1
		Underbench F/F	50	8,760	1	438	438	53	0
IT	87,225 (18%)	Select PC	36		119	315	37,485	4,498	43
		Servers	300	8,760	12	2,628	31,536	3,784	36
		High Perf PC	53		23	460	10,580	1,270	12
		Printer	51		14	444	6,218	746	7
		Other IT Equip	23		7	201	1,406	169	2
Total	494,392								

Figure B1: Breakdown of Estimated Electricity Usage, Cancer Research Centre, University of Edinburgh

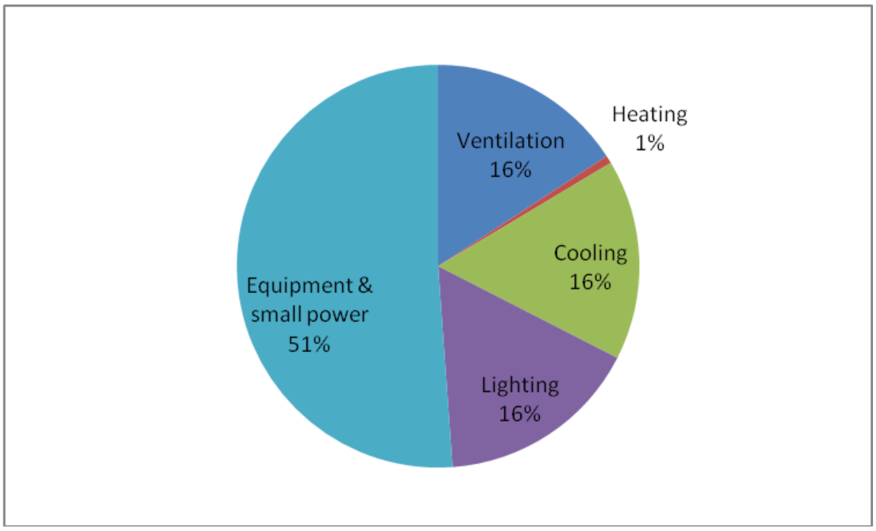


Figure B2: Breakdown of Estimated Total Energy Usage, Cancer Research Centre, University of Edinburgh

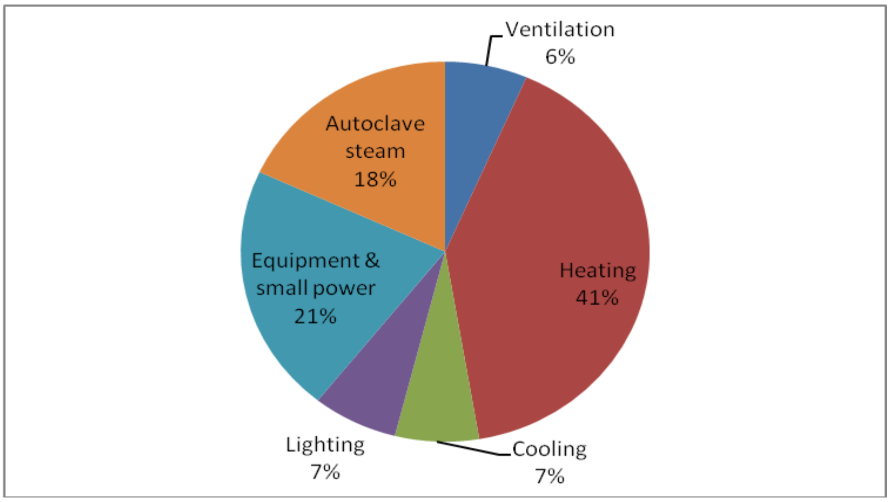


Figure B3: Breakdown of the Estimated Total Energy Usage, Cancer Research Centre, University of Edinburgh (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

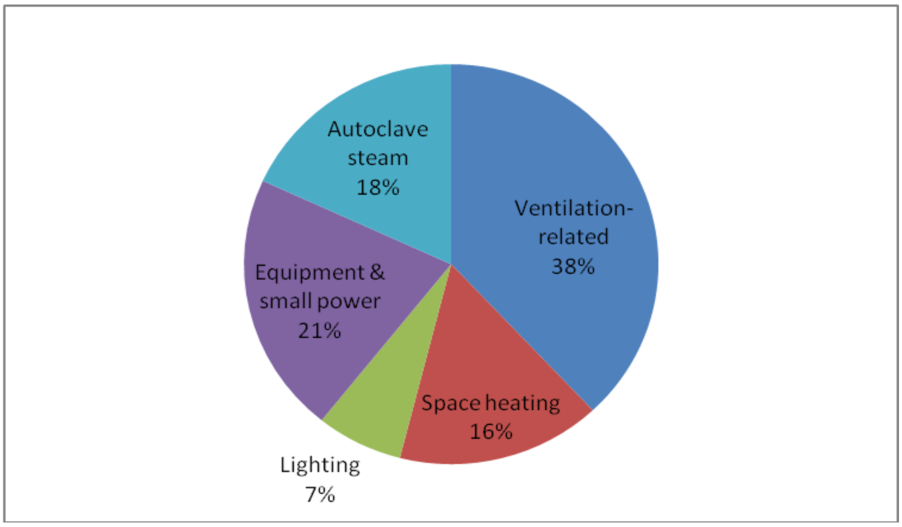


Figure B4: Breakdown of the Estimated Total Energy Usage, Excluding Autoclave Energy, Cancer Research Centre, University of Edinburgh (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

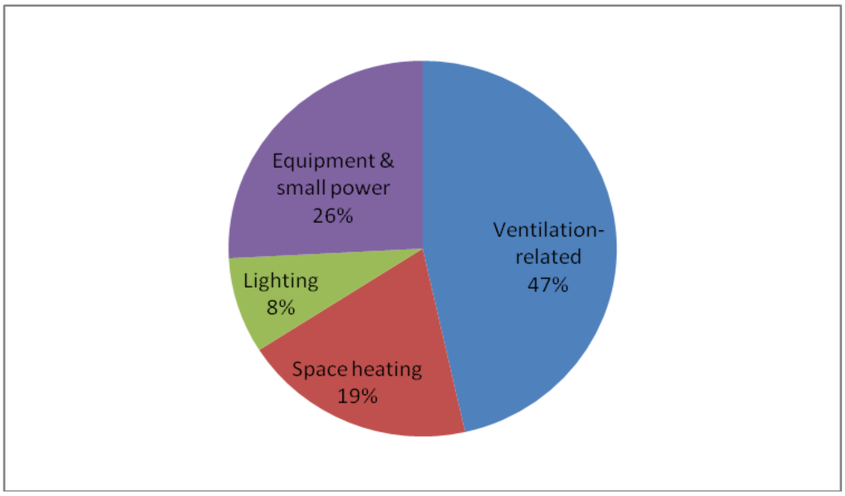


Figure B5: Breakdown of the Estimated Costs Associated with Total Energy Usage, Cancer Research Centre, University of Edinburgh (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

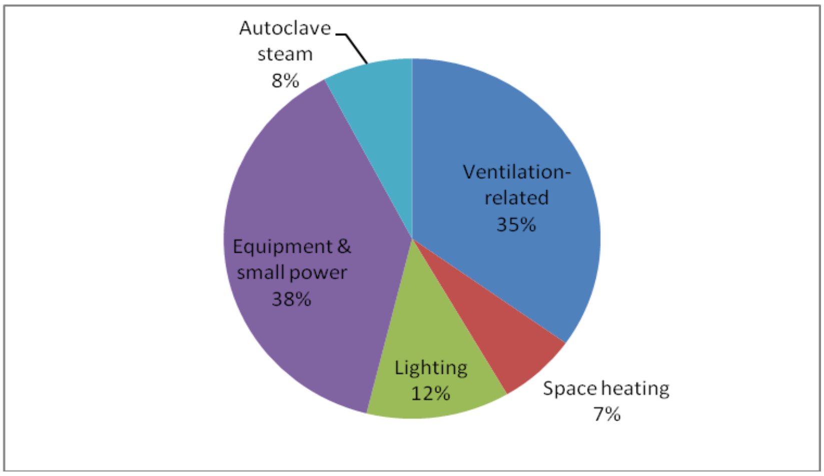
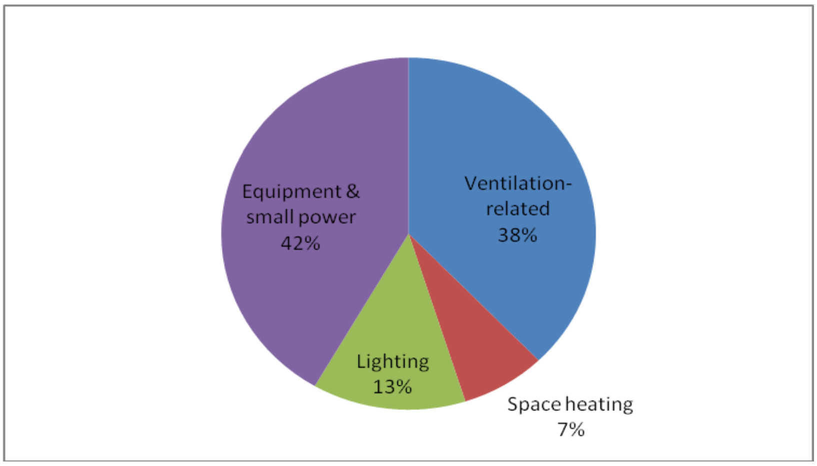


Figure B6: Breakdown of the Estimated Costs Associated with Total Energy Usage, Excluding Autoclave Use, Cancer Research Centre, University of Edinburgh (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)



Appendix C - Energy Consumption in the University of Liverpool's Biosciences Building

The School of Biological Sciences has three buildings which are metered and billed in aggregate.[12] We refer to this building complex as the School complex. Our work focussed on one of these, the Biosciences Building, a 4 storey building of 9,510 sq.m. We did not address Mersey Bio, a facility for start up biotechnology businesses which occupies 1,760 sq.m at one end of the building. We therefore refer to the area investigated as the 'academic section of the Biosciences Building'. This is used for both teaching and research. The offices run along one side of the building separated by a corridor from the lab space. The latter comprises 2 main labs on each floor surrounded by secondary lab areas.

There are only 23 fume cupboards but a number of specially-ventilated areas such as Constant Temperature (CT) rooms, plant growth rooms, cell imaging and microscope rooms. Heating is provided by gas. Two main 370kW chiller units in the roof plant room provide cooling to the whole building, with a third chiller serving specialist rooms. There are a number of split DX units in specialist equipment rooms, including a dedicated -80 freezer room on the ground floor.

C1. Overview

Table C1 provides data for the size and estimated energy consumption of the three School buildings (based on pro rata figures for consistency). It shows that in 2009-10 they:

- Consumed nearly 12 million kWh of energy, comprising around 7 million kWh of electricity and around 5 million kWh of fossil fuel energy.
- Had annual energy costs of £691,791, comprised of £556,679 for electricity (at 8 p/kWh) and £135,111 for gas (at 2.8 p/kWh).

Table C1 also shows that the academic section of the Biosciences Building (which occupies around about 80% of the space):

- Consumes an estimated 5 million kWh of energy, comprising around 3 million kWh of electricity and 2 million kWh of fossil fuel/heat energy.
- Has estimated annual energy costs of £307,489 comprised of £247,434 for electricity and £60,055 for gas.

Table C2 and Figure C1 give a further breakdown of estimated electricity consumption in the academic section of the Biosciences Building. This shows that equipment and small power (mainly lab equipment and IT) accounted for 37%, ventilation 26% and lighting 22% of total electricity.

Table C3 and Figures C2 and C3 provide a breakdown of total energy consumption in the academic section of the Biosciences Building. Figure C3 shows the breakdown when the estimated heating

[12] The total electricity bill for the School of Biological Sciences of around £557,000 includes consumption from Mersey Bio within Biosciences Building, as well as energy from the Life Sciences and NMR buildings.

component of ventilation is included in the ventilation category. This indicates that approximately 43% of the energy consumption of the academic section of the Biosciences Building is associated with moving and conditioning (heating, cooling, humidifying etc.) air.

Figure C4 shows the breakdown for energy costs, when equipment and small power is a much larger component (because of its disproportionate use of electricity, which is more expensive than gas).

Figure C1: Breakdown of Estimated Electricity Usage in the Academic Section of the Biosciences Building, University of Liverpool

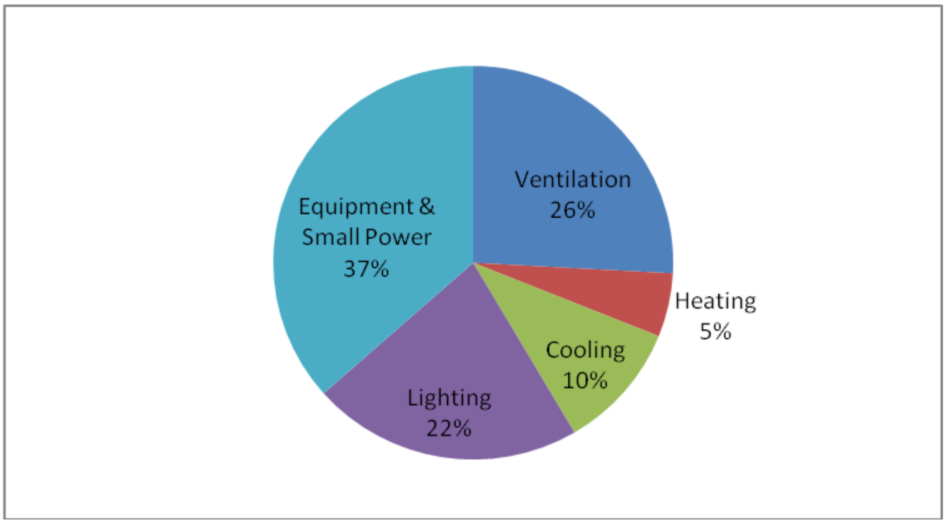


Figure C2: Breakdown of Estimated Total Energy Usage in the Academic Section of the BioSciences Building, University of Liverpool

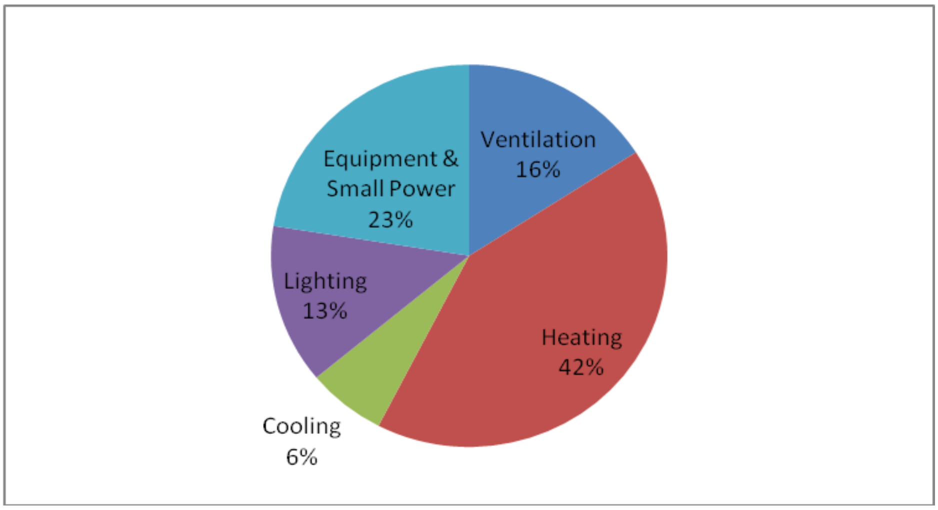


Figure C3: Breakdown of the Estimated Total Energy Usage in the Academic Section of the Biosciences Building, University of Liverpool (with Heating/Cooling Component of Ventilation Included in Ventilation-Related)

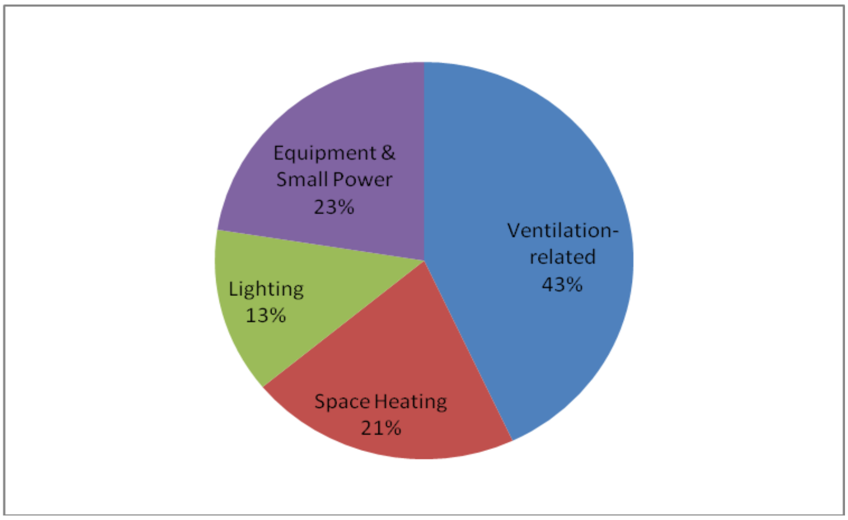


Figure C4. Breakdown of the Estimated Total Energy Costs in the Academic Section of the Biosciences Building, University of Liverpool (with Heating/Cooling Component of Ventilation Included in Ventilation-Related)

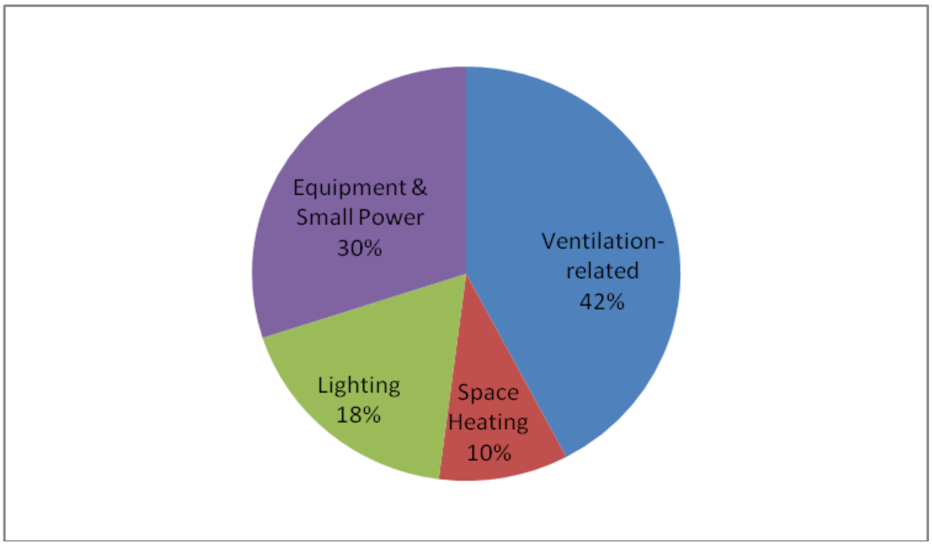


Table C1: Details of Energy Consumption and Costs of the School of Biological Sciences, University of Liverpool, Pro-rated by Floor Area

	Gross Floor Area (sq.m)	**Electricity (kWh/y)**	**Electricity Cost (£/y)**	**Gas/heat (kWh/y)**	**Gas/heat Cost (£/y)**	**Total Energy (kWh/y)**	**Total Energy Cost (£/y)**
Life Sciences	7,550	3,013,112 (a)	241,049	2,089,464	58,505	5,102,576	299,554
Academic Section of the Biosciences Building	7,750	3,092,930 (a) or 3,434,498 (b)	247,434 (a) or 274,760 (b)	2,144,814	60,055	5,237,743 (a)	307,489
Mersey Bio	1,760	702,394 (a)	56,192	487,080	13,638	1,189,475	69,830
NMR	376	150,057 (a)	12,005	104,058	2,913	254,115	14,918
Total School of Biological Sciences	17,436	6,958,493	556,679	4,825,416	135,112	11,783,909	691,791
Annual Energy Consumption per Unit Area (kWh/sq.m/y)		399		276		676	
HEEPI Good and Typical Benchmark for Life Sciences (Excluding Secure Facility)		Good: 242 Typical: 300		Good: 196 Typical: 289			
Annual Energy Cost per Unit Area (£/sq.m/y)			32 (c)		8		40

(a) Metered figure for whole building pro-rated by floor area

(b)Estimate derived from bottom-up calculations (see Table C2)

(c) Based on pro-rated floor area.

Table C2: Estimated Electricity Consumption and Costs in the Academic Section of the Biosciences Building, University of Liverpool)

Category	Sub-category	Consumption (kWh/y)	Cost (£/y)	Basis of Estimate
Ventilation	General Supply	350,252	28,020	AHU(s) 1, 2 & 3 - measured over 7 months (March 2010 to Sept 2010 = 4,752 hrs) then extrapolated to give 12 month data (actual power vs motor rating was 44%).
	General Extract	238,909	19,113	AHU (e) 4, 5 & 6 – ditto.
	Fume Extract	32,377	2,590	22 x fume cupboards & 1 class II cabinet - estimated based on all operating 8760 hrs with 44% motor rated input power.
	Special Area	266,570	21,325	Measured data from 4 active "growth rooms" No 2, 3 5 & 6 over 7 months (34,739 kWh) extrapolated to give 12 month (64,039 kWh). Estimated data: 1. CT Room x 4, FLT LSM x 1 & 4 microscope rooms - estimated fan power based on 8760 hrs x 44% of motor rating 2. Cell Imaging x 2, Cell Sorting x 1, 2 growth rooms which were off - estimated based on 8760 hrs x 44% of motor rating 3. Insectory area AHU's x 5 - estimated based on 8760 hrs x 44% motor rating 4. 22 fan coil units serving - Equipment rooms, Proteomics, Culture rooms, Genomics - estimated fan power based on 8760 hrs x 44% of motor rating.
	Sub-total	888,108	71,048	
Heating		179,875	14,390	Measured data from primary pumps and CT pumps over 3 months, extrapolated for 12 month data (VT pumps excluded - no data - will be small kWh).
Cooling (chillers and pumps)		359,686	28,775	Pumps - estimated based on 7860 hrs x 40% of motor rating. HVAC chillers x 2 - estimated based on COP = 3 and both operating at 33% of capacity 8760 hrs x 41kWe. Process chiller - unknown duty - assumed to be 48kWc and COP = 3, equating to 16kWe operating at 50% duty for 8760 hrs.
HVAC Total		1,427,669	114,213	
Lighting		750,869	60,069	Based on measured data from Lab C pro-rated to whole building, excl. Mersey Bio.
Equipment and Small Power		1,255,961	100,477	Based on measured data from Lab C pro-rated to whole building, excl. Mersey Bio.

Total Electricity Use Estimated from Bottom Up calculations		3,434,498	274,759	Sum of above.
Total Electricity Use Based on Floor Area, Pro Rated		3,092,930	247,434	See Table C1.

Table C3: Estimated Energy Consumption and Costs in the Academic Section of the BioSciences Building, University of Liverpool

Category	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Electricity – Total	3,434,498	274,760	See Table A2. Estimate based on bottom-up calculations.
Electricity – HVAC	1,427,669	114,213	See Table A2 –kWh of ventilation + ventilation-related electrical heating and cooling.
Electricity – Other	2,006,829	160,546	See Table A2 – residual of Total Electricity minus HVAC Electricity.
Gas Consumption Total	2,144,814	60,055	Gas figure for School of Biological Sciences pro-rated by building floor area for Biosciences Building excluding Mersey Bio Based on metered total figure, pro-rated by area – extension = 23% of total building. See Table A1.
Heating (Gas) – Space	1,170,250	32,767	No data available, therefore, assume space heating as a naturally ventilated office = 151 kWh/sq.m/year (Carbon Trust, see footnote 4).
Heating (Gas)- Ventilation	974,564	27,288	Total heating minus space component (equivalent to 45% of heating).
HVAC Energy	2,402,233	141,501	Electricity - HVAC (based on bottom up estimates) plus Heating -Ventilation element.

C2. Plug Load

An inventory of over 1,000 items of lab equipment (including PCs and monitors) in the academic section of the Biosciences Building was conducted, and the rated (peak) power consumption data and estimated usage hours were noted where available. Note that power data for some equipment was inaccessible or unavailable – particularly for large 3-phase or bespoke equipment.

The rated power is likely to overestimate energy consumption and therefore reduction factors were applied to get average energy consumption figures. When organised by total energy consumption, the equipment responsible for the highest energy load were identified, as shown in Table C4. Note that this does not include specialised equipment such as laser microscopes, robotic equipment, mass spectrometers etc.

The figures for total plug load created by this exercise were approximately 16% lower than the estimate obtained by extrapolating metered figures from Laboratory C (given in Table C2). It is not clear how representative Lab C is of the lab equipment in the building as a whole, and which of these methods is more accurate. Nonetheless, Table C4 provides a number of interesting insights, especially:

- Much of equipment energy consumption is associated with heating or cooling, and/or 24/7 operation.
- Equipment which is relatively low powered (e.g. thermal cyclers), but plentiful and frequently used, can be significant.

Table C4: Estimated Annual Electricity Consumption of Selected Equipment in the Academic Section of the Biosciences Building, University of Liverpool

Equipment	Typical Peak Rated power (W)	Assumed Av Power (W) (% reduction factor)	Typical usage (hrs/y)	Typical Energy Consumption per Unit (kWh/y)	Estimated numbers[13]	Estimated Total Energy Consumption (kWh/y)	Estimated Costs (£/y)
Freezer (-20)	1,000	500 (50%)	8,760	4,380	57	249,660	£19,973
Environmental Chamber	2,000 (1,500-2,500)	1,000 (50%)	8,760	8,760	12	105,120	£8,410
Water Bath	1,000 (500 – 1,500)	750 (75%)	4,368	3,276	31	101,556	£8,124
Incubator	850	425 (50%)	8,760	3,723	24	89,352	£7,148
Freezer (-80)	1,200	600 (50%)	8,760	5,256	14	73,584	£5,887
Oven	1,500	495 (33%)	8,760	4,336	11	47,698	£3,816
Ice Maker	2,400	1,200 (50%)	8,760	10,512	3	31,536	£2,523
Hybridiser	750	375 (50%)	8,760	3,285	6	19,710	£1,577
Incubator-shaker	1,500	750 (50%)	3,456	2,592	7	18,144	£1,452
Thermal Cycler (PCR machines)	800 (250-1,600)	400 (50%)	720	288	33	9,504	£760

[13] Approximate figures only

Appendix D - Energy Consumption in the University of Manchester's Chemistry Extension

D1. Overview

The Manchester Chemistry Building has two elements – the main building, built in the 1960s, and a newer extension, built in 2005. As the overall building is both large and complex, the S-Lab audit examined only the extension in detail, which is approximately 25% of the total building floor area. The extension has 3 floors which contain teaching and research labs, a number of specialist lab areas (e.g. mass spectrometry room), computer suites and network hubs.

Heating is by natural gas. Cooling is provided by 2 chillers and a number of split DX units in individual rooms. The extension has 102 fume cupboards designed as Variable Air Volume (VAV) with a face velocity of 0.5 m/s, though in practice they operate with a 0.6 m/s face velocity. Due to diversity constraints, a maximum of 69 fume cupboards can operate at any one time when their sashes are fully open.

As Table D1 shows, the Chemistry Extension in academic year 2009-10:

- Consumed an estimated 2.5 million kWh of energy, comprising around 0.9 million kWh of electricity and 1.6 million kWh fossil fuel energy (mainly gas for heating).
- Had annual energy costs of around £107,000 comprised of around £70,000 for electricity (at 7.95 p/kWh) and £37,000 for gas (at 2.3 p/kWh).

Table D2 and Figure D1 show that the main component of electricity demand is estimated to be ventilation (52%) followed by equipment and small power (largely lab equipment and IT) (22%).

Table D3 and Figures D2 and D3 show that, combined, fossil fuel and electrical heating account for an estimated 63% total energy (see Fig D2). However a majority of heating energy is used to heat the air which passes through the ventilation system – when this is taken into account ventilation related consumption accounts for 61%, and space heating 22%, of overall energy demand (see Figure D3).

Table D4 shows that fume cupboards are responsible for the majority of ventilation-related consumption. They consume an estimated 20,159 kWh/year, or £891/year per fume cupboard. This low figure is partly explained by lack of cooling in the laboratory.

Table D1: Details of Energy Consumption and Costs of the Chemistry Building, University of Manchester, Pro-rated by Floor Area

	Gross Floor Area (sq.m)	**Electricity (kWh/y)**	**Electricity Cost (£/y)**	**Gas (kWh/y)**	**Gas Cost (£/y)**	**Total Energy (kWh/y)**	**Total Energy Cost (£/y)**
Main Building	12,807	4,545,593 (a)	361,847	5,386,037 (b)	123,879 (b)	9,931,630	485,726
Extension	3,816	883,407 (c) 1,010,037 (d)	70,231	1,604,835 (b)	36,911 (b)	2,488,242	107,142
Total Building	16,623	5,429,000	432,170	6,990,872	160,790	12,419,872	592,960
Annual Consumption per Unit Area (Extension) (kWh/sq.m/year)		232		421 (as per total building)		652	
Annual Consumption per Unit Area (Total Building) (kWh/sq.m/year)		327		421		747	
HEEPI Energy Benchmark for Chemistry (kWh/sq.m/year)		Typical: 367		Typical: 353			
Annual Cost per Unit Area (Extension) (£/sq.m/year)			18		10		28
Annual Cost per Unit Area (Total Building) (£/sq.m/year)			26		10		36

(a) Residual of total building minus extension figures

(b) Metered data pro-rated by floor area

(c) Based on metered data

(d) Estimate derived from bottom-up calculations (see Table D2)

Table D2: Estimated Electricity Consumption and Costs in the Chemistry Extension, University of Manchester

Category	Sub-category	Consumption (kWh/y)	Cost (£/y)	Basis of Estimate
Ventilation	General Supply	155,214	12,339	Measured data for 7 months, extrapolated to give 12 months.
	General Extract	38,426	3,055	Measured data for 7 months, extrapolated to give 12 months.
	Fume Extract	335,000	26,633	Measured data for 7 months, extrapolated to give 12 months.
	Sub Total	528,640	42,027	Measured data for Supply AHUs, General Extract AHUs & Fume Extract Fans - 7 months data for all excluding AHU 05 (2 months) then extrapolated for 12 months.
Heating		35,864	2,851	Measured data for primary, CT & VT pumps over 7 months, extrapolated to give 12 months.
Cooling		6,463	514	Measured data for AHU 01 chiller, 4 months, extrapolated for 12 months & local AC units measured data for 5 months, extrapolated to give 12 months.
HVAC	Sub-total	570,967	45,392	Sum of Ventilation, heating and cooling above.
Central Services	Compressed Air	10,357	823	Common system serving main chemistry and extension – taking 23% of total measured data, for 7 months, extrapolated to give 12 months then pro-rated on total area 16,623sq.m and 3816sq.m for extension. Included in 'Equipment and Small Power' category in charts.
	Vacuum	17,978	1,429	
	Nitrogen	56,662	4,505	
	Sub-total	84,997	6,757	
Lighting		134,301	10,677	12 months measured data excluding MG, M1 & M2.
Equipment and Small Power		219,773	17,472	12 months measured data – PG1 & 2, P1/2 & 2/2, P2/1 & P2/2, MG, M1 & M2.
Total Estimated Electricity Consumption		1,010,037	80,298	Sum of bottom up calculations above: HVAC plus central services plus lighting plus small power.
Total Actual Electricity Consumption		883,407	70,322	Derived directly from meters (see Table 1).

Table D3: Estimated Energy Consumption and Costs in the Chemistry Extension, University of Manchester

Category	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Electricity – Total	1,010,037	80,298	See Table D2. Estimate based on bottom-up calculations.
Electricity – Ventilation	528,640	42,027	See Table D2.
Electricity – HVAC	570,967	45,392	See Table D2 : Ventilation plus Heating plus Cooling
Electricity – Other	439,071	34,906	See Table D2: Central Services plus Lighting plus Small power.
Gas Consumption (Total)	1,604,835	36,911	Table D1. Based on metered total figure, pro-rated by area of Extension 23% of total.
Heating (Gas) – Space	576,216	13,253	Assumed space heating as a naturally ventilated office = 151 kWhrs/ sq.m/year (ECG83 – Energy Use in Government Labs 2002) x 3816sq.m.
Heating (Gas) - Ventilation	1,028,619	23,658	Total natural gas heating minus space component.
HVAC Energy	1,599,586	69,050	Electricity-HVAC plus Heating-HVAC Element.

Table D4: Estimated Fume Cupboard Energy and Costs in Chemistry Extension, University of Manchester

Element	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Fume Extract Fans	335,000	26,633	Figure from Table D2
Supply AHU's – Fans	130,495	10,374	84% of the figure for general supply AHUs (= 155,214 kWh) in Table D2, reflecting the difference between the fume extract design flow of 31.2 m^3/s and the total design flow rate of 37.11 m^3/s (i.e. 6.09 m^3/s is providing general ventilation rather than feeding the extract). Actual figures may differ in practice.
General Extract Fans	38,426	3,055	Figure from Table D2.
Heating Pumps	22,953	1,824	64% of the total heating pump power 35,864 kWh given in Table D2, i.e. it was assumed that 36% of the load was related to space heating, as per Table D3.
Fresh Air - Heat only (no cooling or (de)humidification	864,805	19,890	84% of the natural gas heating associated with ventilation (1,028,619 kWh – see Table D3) i.e. pro-rated based on fume extract flow compared to total design flow rate.
Total Fume Cupboards	1,391,679	61,476	
Per Fume Cupboard	20,159	891	For 69 fume cupboards at 0.6 m/s face velocity

Figure D1: Breakdown of Estimated Electricity Usage in Manchester Chemistry Extension

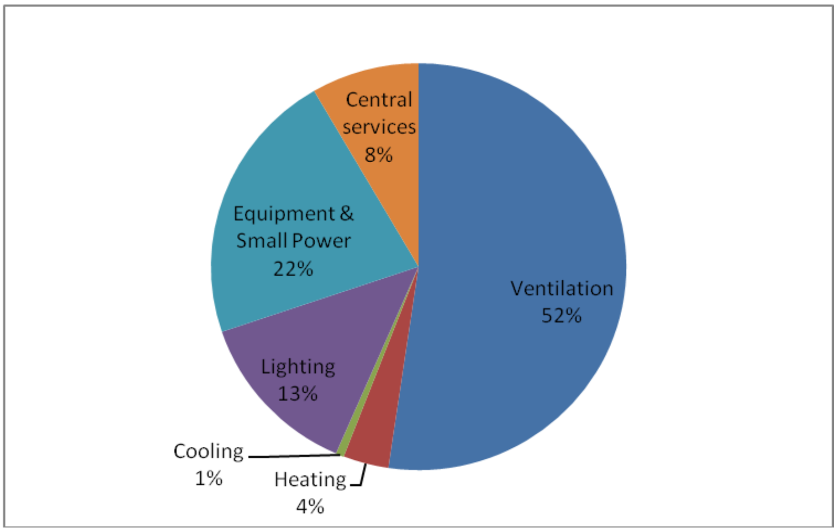


Figure D2: Breakdown of Estimated Total Energy Usage in Manchester Chemistry Extension

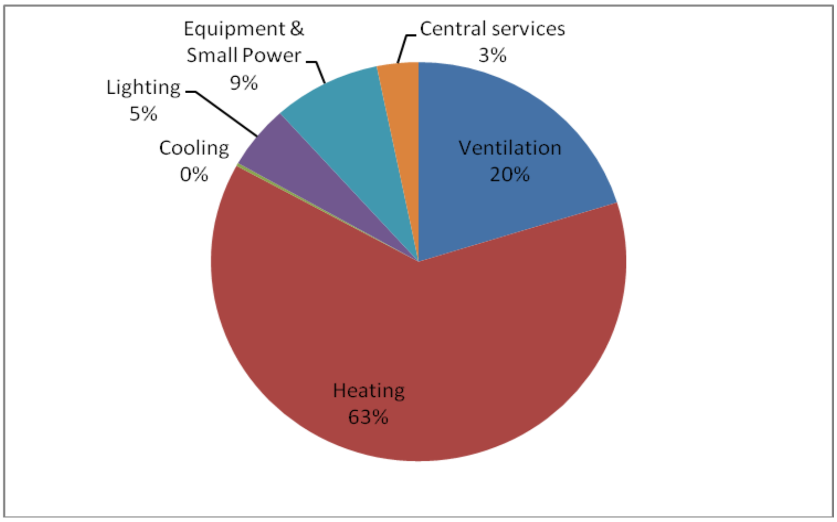


Figure D3: Breakdown of Estimated Total Energy Usage in Manchester Chemistry Extension (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

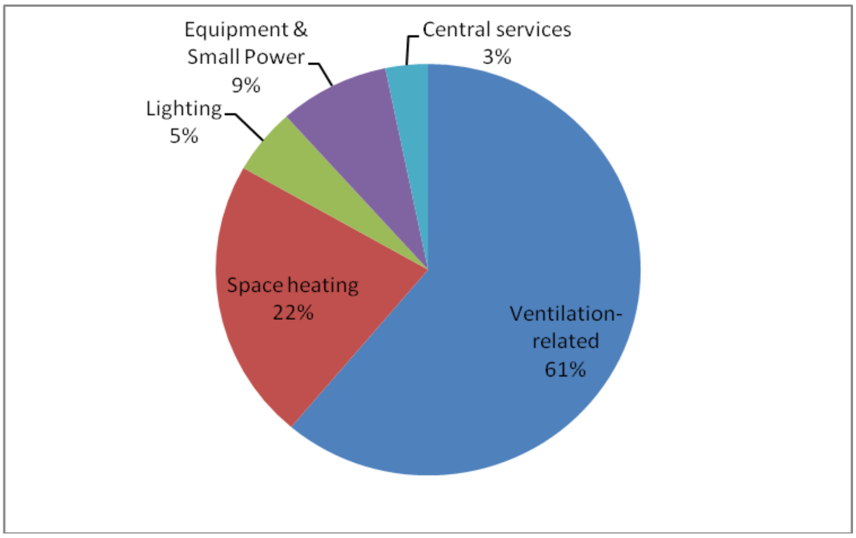
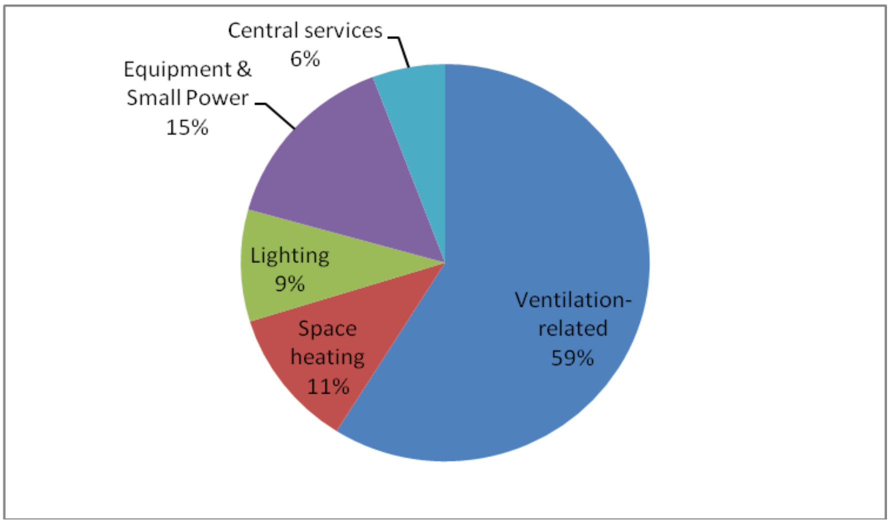


Figure D4: Breakdown of the Estimated Costs Associated with Total Energy Usage, Manchester Chemistry Extension (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)



D2. Plug Load

As Table D5 shows, an inventory of lab equipment in the Extension was conducted, and the rated (peak) power consumption data noted where available. Note that power data for some equipment was inaccessible or unavailable – particularly for large 3-phase or bespoke equipment. As much equipment is seldom operated at full power, a figure was generated for average power consumption. Usage patterns were also estimated.

When organised by total energy consumption, the equipment responsible for the highest energy load were identified, as shown in Table D5. The figures for total plug load created by this exercise were approximately 45% greater than the measurement of laboratory small power energy consumption derived from meters (as shown in Table D2) so the exercise is clearly indicative rather than exact. Nonetheless, Table D5 provides a number of interesting insights, especially:

- Consumption associated with equipment which is low powered but plentiful can be as significant in total as more obvious items of larger equipment.
- Much of equipment energy consumption is associated with heating or cooling, and/or 24/7 operation.

Table D5: Estimated Annual Electricity Consumption of Selected Equipment in the Chemistry Extension, University of Manchester

Equipment	Typical Peak Rated Power (kW)	Assumed Average Power (kW) (with % reduction factor)	Typical Usage (hrs/y)	Typical Energy Consumption per Unit (kWh/y)	Estimated Numbers[14]	Estimated Total Energy Consumption (kWh/y)	Estimated Costs (£/y)
Heaters/Stirrers	0.5	0.375 (75%)	648	243	200	48,600	£5,832
Mass Spectrometry	3	1 (33%)	8,760	8760	5	43,800	£5,256
Gas Chromatography	1.6	0.8 (50%)	8,760	7008	4	28,032	£3,364
Rotary Evaporators	1.76	0.59 (33%)	1,000	590	27	15,930	£1,912
NMR	3.52	1.76 (50%)	8,760	15,418	1	15,418	£1,850
Ovens (Chemical)	6	2 (33%)	432	864	12	10,368	£1,244
Fridges	0.1	0.1	8,760	876	5	4,380	£526
Diaphragm Pumps	0.37	0.12 (33%)	1,000	120	26	3,120	£374
Vacuum Pumps	0.25	0.1875(75%)	216	40.5	60	2,268	£272
Water Baths (Large)	1.5	1.125 (75%)	72	81	28	2,025	£292

[14] Approximate figures only

Appendix E - Energy Consumption in the University of York's Department of Biology

E1. Overview

The Department of Biology has eleven blocks which are metered in various ways and billed in aggregate. This audit focussed on 3 blocks within the Department: K, L and M, which are responsible for the majority of the energy consumption. Table E1 is a summary table of the derived energy consumption for K, L and M blocks. Table E2 summarises the sub-metered data available for the Department as an illustration of a not atypical sub-metering strategy in laboratories , and how difficult it can sometimes be to disaggregate data between different uses. In the cases of Blocks K, L and M, this involved pro-rating the data based on floor area. Therefore the data presented in Tables E3, E4 and E5 represent best estimates in the time available.

Table E3 provides data for the size and estimated energy consumption of blocks K, L and M.[15] It shows that in calendar year 2009 they:

- Consumed nearly 9 million kWh of energy, based on calendar year 2009 data, comprising around 5 million kWh of electricity and around 4 million kWh of gas
- Had annual energy costs of around £530,000, comprised of £370,000 for electricity (at 7.43 p/kWh) and £97,000 for gas (at 2.5 p/kWh).

Table E3 and Figure E1 give a further breakdown of electricity consumption in the three blocks. This shows equipment and small power (largely lab equipment and IT) account for 31%, cooling 22%, lighting 18% and ventilation 17% of total electricity use.

Table E4, and Figures E2 and E3, give an estimated breakdown of total energy in the three blocks. Figure E3 shows the breakdown when the heating/cooling component of ventilation is included in the ventilation category. This indicates that approximately 45% of the energy consumption of the 3 blocks is associated with moving and conditioning (heating, cooling, humidifying etc) air.

Table E4 shows the estimated HVAC energy of around 3.8 million kWh costs around £200,000/year.

Figure E4 shows that ventilation-related energy costs are 44% of the total and equipment and small power 24%.

[15] The figures include the energy consumption of the air handling unit which serves another block, F2, as this was sub-metered together with the lighting and plug load for Block L and it was difficult to separate its consumption out. It is unlikely to be more than 3-4% of the estimated total.

Table E1: Details of Energy Consumption and Costs of Department of Biology, University of York

	Block served	**Gross Internal Area (GIA) (sq.m)**	**Electricity (kWh/y)**	**Electricity Cost (£/y)**	**Gas (kWh/y)**	**Gas Cost (£/y)**	**Total Energy, (kWh/y)**	**Total Energy Cost (£/y)**
Total Consumption of Blocks K, L, M, P and F2 from Primary Meters	K, L, M & F2 +P (Greenhouse)	14,448	5,886,146	£437,341	3,892,492	97,312	9,778,638	£534,653
F2 & P Chiller Energy	F2 & P		208,976 (a)					
F2 & P Plug Load and Lighting	F2 & P		652,784 (b)					
Consumption of Blocks K, L and M after Exclusion of Block F2 and P Data	K, L and M	12,740	5,024,386 (c)	£373,312	3,635,922 (d)	90,898 (d)	8,660,308	464,210
Annual Consumption per Unit Area (Blocks K,L,M)(kWh/sq.m/y)			394		285		679	
HEEPI Energy Benchmark for Life Sciences (Excluding Secure Facility)			Good: 242 Typical: 300		Good: 196 Typical: 289		Good: 438 Typical: 589	
Annual Cost per Unit Area (Blocks K,L,M) (£/sq.m/y)				29		7		36

(a) Electricity for chillers 1,2, 3 (see Table E2) pro-rated by supply air to F2 & P compared to K,L,M,F2 & P

(b) See Table E2, sub-meters for P and F2

(c) Value for K, L, M, F2 & P (line 1) minus F2 & P chiller (line 2) minus F2 & P plug and lighting (line 3)

(d) Value for K, L, M, F2 & P gas (line 1) pro-rated by floor area for K,L,M

Table E2: Sub-Metered Data for the Department of Biology, University of York

Meters	Block served	Gross Internal Area (GIA) (sq.m)	Electricity (kWh/y)	Electricity Cost (£/y)	Gas (kWh/y)	Gas Cost (£/y)	Total Energy (kWh/y)	Total Energy Cost (£/y)
Primary meters	K, L, M & F2 +P (Greenhouse)	14,448	5,886,146	437,341	3,892,492	97,312	9,778,638	534,653
Block K - Plug & Lighting	K	5,802	1,079,681	80,220				
Block M – Plug, lighting & HVAC	M	3,469	1,127,030					
Block K – Mechanical Panel (K plant room AHUs & bioscience wide pumps & controls)	K	7,509	1,043,602	77,540				
Block L -–Plug + Lighting + HVAC (incl. F2 AHU but excl. BSF plug load & lighting)	L & F2	4367	1,197,979	93,127.47				
Chiller 1	K, L, M, F2 & Greenhouses	14,448	402,646	29,917				
Chiller 2	As above		376,051	27,941				
Chiller 3	AS above		6,373	474				
Block F2 – Plug Load and Lighting (new meter)	F2 plug load and lighting	898	55,419	4,118				
P: Greenhouse	Greenhouse	809	597,365	44,384				

Table E3: Estimated Electricity Consumption and Costs in Blocks K, L, & M of the Department of Biology, University of York

Category	Sub-category	Consumption (kWh/y)	Cost (£/y)	Basis of Estimate
Ventilation	General Supply	389,808	£28,963	Estimate based on running hours and nameplate motor rating. Reduced by 60% to take account of difference between rated and actual power consumption.
	General Extract	248,875	£18,491	As above.
	Fume Extract	105,295	£7,823	As above.
	Plant room & lift motor room S/E	77,312	£5,744	As above.
	Sub-total	821,291	£61,022	Sum of ventilation sub-categories.
Heating		204,940	£15,227	Pro-rata common service pumps using floor area.
Cooling (chillers & pumps)		1,093,367	£81,237	Pro-rata chillers based on AHU airflow rate.
HVAC Total		2,119,598	£157,486	
Central Services		77,438	£5,754	Cooling water pumps: motor nameplate data assumed 100% run time.
Lighting & Small Power (sum of two categories below)		2,369,640	£176,064	Based on 186 kWh/ sq.m/year as block K metered light & small power, applied to K,L and M.
Lighting		876,767	£65,144	Assumed lighting/small power ratio as for Liverpool, i.e., lighting 37%.
Equipment and Small Power		1,492,873	£110,920	Assumed lighting/small power ratio as for Liverpool, i.e., small power 63%.
IT (server rooms)		292,886	£21,761	Estimate based on triffid monitoring for circuit which includes server rooms.
Total Electricity Consumption from Bottom-up Calculations		4,859,563	£361,066	Sum of HVAC plus central services, lighting, small power and server energy.
Total Electricity Consumption from Metered Data		5,024,386	£373,312	See Table E1.

Table E4: Estimated Energy Consumption and Costs in Blocks K, L and M of the Department of Biology, University of York

Category	**Consumption (kWh/y)**	**Cost (£/y)**	**Basis of Estimate**
Electricity – Total	4,859,563	£361,066	See Table E3 based on bottom up estimates.
Electricity – HVAC	2,119,598	£157,486	See Table E3 –kWh of ventilation + ventilation-related electrical heating and cooling.
Electricity – Other	2,739,965£	£103,580	See Table E3 – residual from HVAC.
Gas Consumption – Total	3,635,922	£90,898	See Table E2 – gas figure for K, L, M & F2 pro-rated by floor area.
Heating (Gas) – Space	1,923,740	£48,094	No data available, therefore, assume space heating as a naturally ventilated office = 151 kWh/sq.m/year (Carbon Trust, see footnote 4).
Heating (Gas)- Ventilation	1,712,182	£42,805	Total heating minus space component (equivalent to 47% of heating).
HVAC Energy	3,831,780	£200,291	Electricity - HVAC plus Gas Heating - Ventilation element.

Figure E1: Breakdown of Estimated Electricity Usage, Blocks K, L & M, Dept Biology, University of York

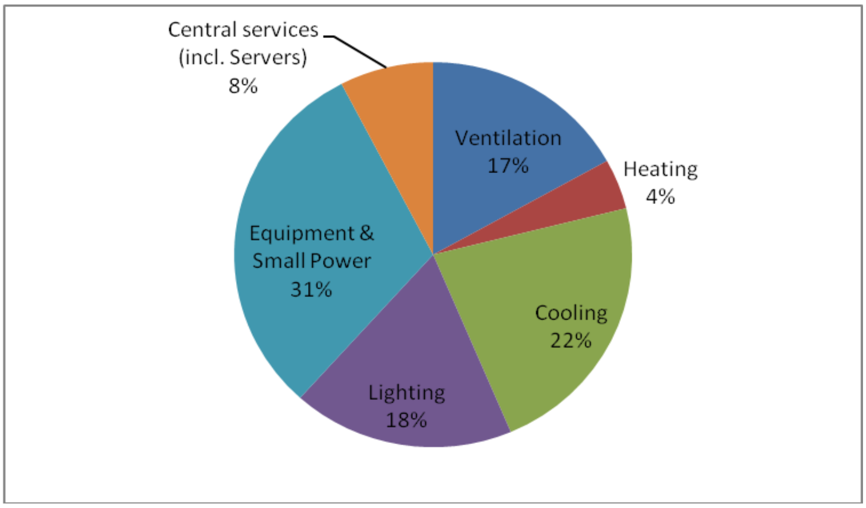


Figure E2: Breakdown of Estimated Total Energy Usage, Blocks K, L & M, Dept Biology, University of York

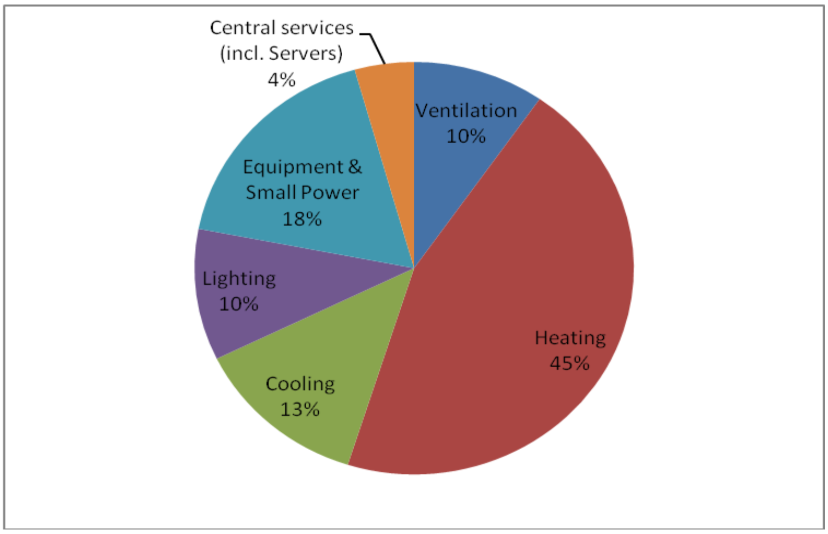


Figure E3: Breakdown of Estimated Total Energy Usage, Blocks K, L & M, Dept Biology, University of York (With Heating/Cooling Component of Ventilation Included in Ventilation-Related)

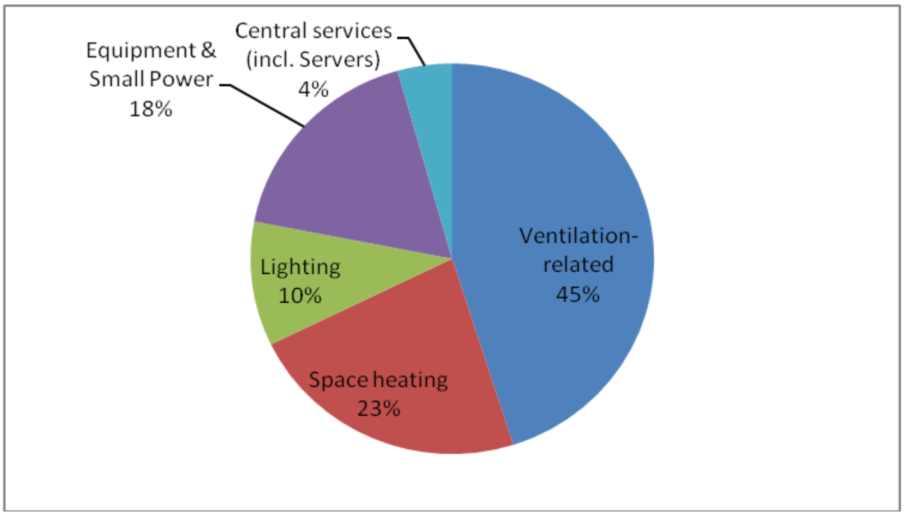
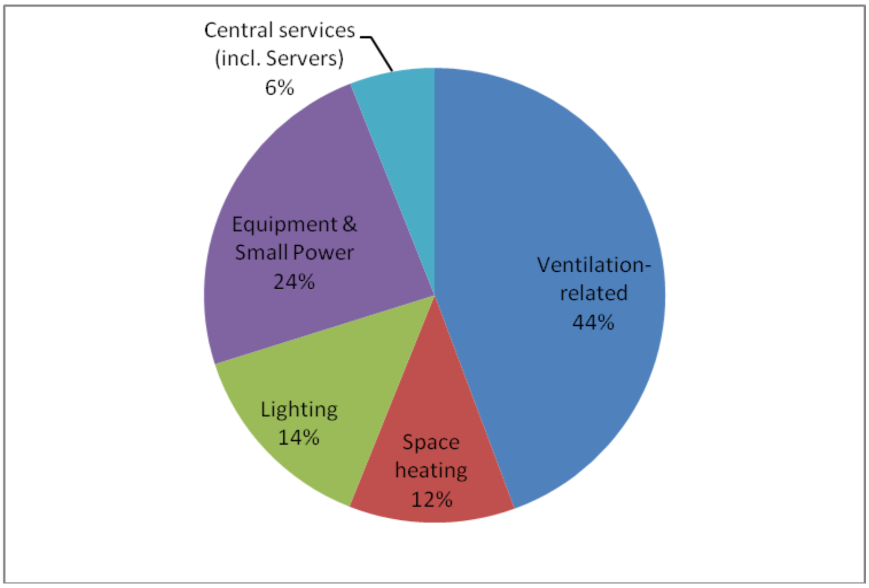


Figure E4: Breakdown of the Estimated Costs Associated with Total Energy Usage, Blocks K, L, M, University of York (with Heating/Cooling Component of Ventilation included in Ventilation-related)



E2. Plug Load

A detailed survey of rated power/usage of lab equipment was not carried out for this audit as the Biology Department's then Energy Manager, Jo Hossell, had already monitored a number of individual equipment items and had actual consumption data, which is more accurate.

Table E5 provides info on those items that she monitored, plus estimated energy use data on certain items of equipment based on energy assessments from another bioscience laboratory. This shows that -80 freezers, growth cabinets and incubators are the main items of equipment responsible for equipment energy consumption.

Table E5: Estimated Annual Electricity Consumption of Selected Equipment in Blocks K, L, M of Dept Biology, University of York

Equipment	Measured Actual Consumption (kWh/y)	Measured Average Consumption (kWh/y)	Typical Usage (hrs/y)	Estimated Energy Consumption per Unit (kWh/y)	Estimated Numbers (approximate figures only)	Estimated Total Energy Consumption (kWh/y)	Estimated Costs (£/y)
-80 Freezer		5,724	8,760	3,990 (a)	47	269,046	£19,990
Growth Cabinet (small)		9,548	8,760	9,548 (b)	>22	210,065	£15,608
Incubator (shaken & not)				2,592 (f)	66	171,072	£12,711
Drying Cabinet			1,825	5,630 (c)	24	135,120	£10,039
Water Bath (boiling)	7,018		2,555		13	91,234	£6,779
Oven				4,336 (f)	11	47,696	£3,544
Water Bath (60°C)	1,327		2,555		24	31,848	£2,366
Ice Maker				10,512 (f)	3	31,536	£2,343
Biological Safety Cabinet				3,373 (d)	7	23,611	£1,754
-20°C Freezers		313	8,760	313	50	15,677	£1,165
Vending Machines			5,840 (e)		7	15,645	£1,162
PCR				288 (f)	4	1,152	£86

(a) Average measured energy consumption based on 7 freezers. This will vary by freezer capacity. There are 47 -80Cs costing an estimated £0.97/litre to run with an average capacity of 524 litres, so estimated total consumption is 269,046kWh/year with an estimated average of 5,724kWh. This is based on metering of 27 of them and knowing all makes and capacities – so for ones that have not been metered, figures from one of the same make and size that have been metered have been used.

(b) Only 25 are in use at the moment the rest are turned off –where possible these are switched to take advantage of a reduced night time tariff so they run lights from about 2:00am.

(c) Measured energy consumption of a small drying cabinet.

(d) Measured energy consumption of 2 safety cabinets.

(e) Measured energy of 7 vending machines.

(f) These are not measured figures – estimated consumption based on rated power and estimated usage.

Appendix F - Sources of Information

The main sources of information were:

Metered data. For some of the labs a metered figure was available for the total electricity and gas consumption, or for a particular sub-category (e.g. lighting).
Metered data, pro-rated by floor area. In many cases a metered figure was available for a particular category for part of the lab (e.g. lighting on one floor or one lab area) which was then extrapolated to the whole lab based on floor area. In some cases, because the lab audit focussed on part of a single building, or the building itself was not separately metered, the total energy consumption also had to be pro-rated by floor area.
Metered data, pro-rated by air supply. In one case, York chiller energy, the metered data was pro-rated by air supply, which was felt to be more accurate than by floor area.
Inverter readings. For some of the labs inverters controlling the fans and pumps were manually monitored by the Estates Department and power output data shared with S-Lab.
Bottom-up estimates based on the product of plant/equipment rated power (W) and usage (hrs/y). This method was used in the absence of metered data but often tends to overestimate energy e.g. it was found that initial bottom-up estimates of electrical ventilation energy (fans) were 60% higher than metered data in two of the labs audited. For this reason ventilation energy consumption estimates for two of the labs (Edinburgh and York) where there was no sub-metering were reduced by 60%. Similarly bottom-up estimates of lab equipment will also be higher (in some cases 50% higher) than the actual consumption. Again a reduction factor was applied to bottom-up estimates of lab equipment at Edinburgh, where there were no metered data estimates. Chiller energy at some of the labs was also estimated using rated power and percentage of year runtime.
Use of typical benchmark figures. Benchmark figures for lighting and IT were used in several cases in the absence of any metered data. A Carbon Trust benchmark figure for space heating was also used to differentiate the gas consumption used for space heating from that used for ventilation heating.
Residual data. In some cases, e.g. lab equipment at Cambridge, the energy consumption was simply a residual of the difference between total energy consumption and bottom up estimates.

Table F1 shows the different ways in which the total and breakdown of energy consumption was estimated at the different labs.

S-Lab considers the data provided on the five laboratories in the Appendices to be the best available in the absence of full sub-metering. However, because of the many assumptions made the error margins in the estimates are unknown and potentially considerable. There is also a high degree of variability in different labs even within the same discipline, and even the same lab at different times (due to the ever changing nature of science and research). Therefore care is advised in applying these results too directly to other laboratories.

Table F1: Methodology Used for Estimating Energy at Different Laboratories

Energy Category	**Life Science Laboratories**			**Chemistry Laboratories**	
	Edinburgh	**Liverpool**	**York**	**Cambridge**	**Manchester**
Year for energy data used	Academic year 2009/10	Calendar year 2009	Calendar year 2009	Academic year 2007/08	Academic year 2009/10
Electricity:					
Total	Metered figure	Metered figure pro-rated by floor area	Metered figure pro-rated by floor area	Metered figure	Metered figure pro-rated by floor area
Ventilation	Bottom up estimate reduced by 60%	Sub metered	Bottom up estimate reduced by 60%	Bottom up estimate (a)	Sub metered
Heating	Bottom up estimate	Bottom up estimate	Metered figure pro-rated by floor area	Bottom up estimate	Sub-metered
Cooling	Bottom up estimate	Bottom up estimate	Sub-metered figure pro-rated by air supply	Bottom up estimate	Sub-metered
Equipment and small power	Bottom up estimates of energy intensive equipment only	Sub-metered figure for one lab area pro-rated to whole lab	Sub-metered data for equipment	Residual from total	Sub-metered
Lighting		Sub-metered figure for one lab pro-rated up	Allocated according to ratio at Liverpool	benchmark	Sub-metered
Central services	n/a	n/a	Sub-metered data pro-rated by floor area	Residual included in Equipment category	Sub-metered
Server room	n/a	n/a	Sub-metered data adjusted by estimate based on triffid monitoring	Bottom-up estimates	n/a

Gas:					
Total	Metered figure	Metered figure pro-rated by floor area	Metered figure pro-rated by floor area	Metered figure	Metered figure pro-rated by floor area
Space heating	Benchmark figure used	Benchmark figure used	Benchmark figure used	Sub-metered data	Benchmark figure used
Ventilation-related	Residual figure	Residual figure	Residual figure	Residual figure	Residual figure
Steam (autoclave)	Regression analysis to find typical gas consumption in summer months x 12	n/a	Included in Equipment and Small Power category	n/a	n/a

(a) This figure was not reduced as it was felt to be reasonably accurate as it included standby power.