Maintaining quality and reducing energy in research animal facilities

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Summary
Laboratory Animal facilities need to make careful choices in design, equipment and working practices to create a more sustainable working environment. It is important that any new or refurbished project provides high quality barriered facilities meeting the needs of science and housing large numbers of animals.

There are many synergies between sustainability and better working conditions for staff and animals. Natural daylight and ventilation (in staff areas) and use of sustainable materials, have positive psychological effects on most users, may help to minimise unpleasant noise and are associated with increased productivity and reduced absenteeism.

There is growing recognition of the need to make laboratories more sustainable. The US Labs 21[1] initiative, established by the Department of Energy and Environmental Protection Agency, has developed much guidance material and is now having a major influence on lab design in North America. A number of North American laboratories are using their compliance with this guidance to emphasise their environmental commitment and world class status; to minimise their operating costs and potential liability and to enhance their facility's attractiveness to staff, thereby aiding productivity, recruitment and retention. A UK initiative has also been established and is developing similar guidance for the British context as well as working with its equivalents in other European Countries, such as the German Laboratory 2020 programme, to develop an EU initiative. Labs21 UK aims to reduce these and other environmental impacts through the sharing of best practice by benchmarking and other means. The work builds on the Labs21 programme of the US, which has demonstrated that a new approach to design and operation can result in significant environmental, financial and other benefits.

Introduction
This paper sets the scene for carbon reduction and reviews current data from research facilities to answer two fundamental questions. Firstly, how achievable are energy reduction targets in animal facilities? Secondly, can Laboratory Animal facilities cut their energy consumption to meet targets and still maintain a high quality environment when some recently completed new animal facilities use increased energy to meet the needs of higher capacity and improved environmental conditions? Aside from environmental considerations there are clear economic implications. It appears that many UK customers of new and refurbished laboratories – and especially those in higher education – are not getting 'value for money'. Their utility and other operating costs could be significantly lower than at present without compromising safety and performance. Indeed, the central message of Labs21 is that there are strong synergies between sustainable laboratories, safe laboratories and productive laboratories.

Background
There are a number of drivers behind sustainable buildings including minimisation of carbon footprint, which is a key UK Government policy whose requirements are becoming increasing strict. The Climate Change Bill[2] will establish legally binding targets of at least 26% by 2020 and at least 80% by 2050, compared to 1990 levels, and these are now cascading down. Government laboratories have their own target of reducing its estates-related carbon emissions by 30% in 2030 compared to 1990 levels under the Sustainability of the Government Estate (SOGE) initiative. This also requires zero carbon in Government offices – there is also evidence of considerable differences in energy consumption between laboratories.

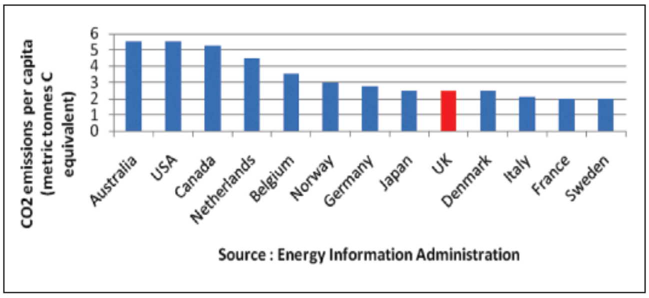

Figure 1. CO_2 emissions per capita

This table illustrates how the UK compares with other western countries and Japan on CO_2 emissions per captia. France's high use of nuclear power is one of the reasons for their low emissions. Japan after recent problems has increased use of fossil fuel to generate power.

Australia	5-25% below 2000 by 2020
USA	Return to 1990 by 2020
Canada	20% below 2006 by 2020
Japan	25% below 1990 by 2020
Scotland	42% below 1990 by 2020
South Korea	30% relative to BAU by 2020
United Kingdom	34% below 1990 by 2020
Regional Greenhouse Gas Initiative (North-Eastern US and Canada)	10% below 1990 by 2020
Brazil	36% relative to BAU by 2020
China	40-45% reduction in emissions per unit of GDP by 2020 compared to 2005 levels
India	20-25% reduction in emissions per unit of GDP by 2020 compared to 2005 levels
Indonesia	26% relative to BAU by 2020

Figure 2. Emission reduction targets by country

The table (Figure 2) demonstrates how many countries are now pursuing reductions in emissions. These targets require fundamental changes in how energy is used. Targets may differ and change but the fundamental drivers to reduce emissions are clear. But increasingly economic, in addition to environmental, conditions are driving change.

Laboratories have many environmental impacts. One of the most serious is their consumption of large quantities of energy – up to ten times more than offices on a square metre basis – and water. Fans consume 40-50% of the total electrical consumption because of high ventilation load. An additional 10-30% of energy consumption can be used to chill air or water to cool spaces or equipment. High utility consumption is expensive, not only in energy and water bills but also through the associated capital, maintenance and other expenditure needed to supply the required cooling and ventilation. There is growing evidence that some of this expenditure can be avoided through effective design without compromising, and indeed enhancing, safety. However, relatively few UK laboratories are achieving this, especially in higher education, in animal research facilities.

UK University campuses have many pressures to

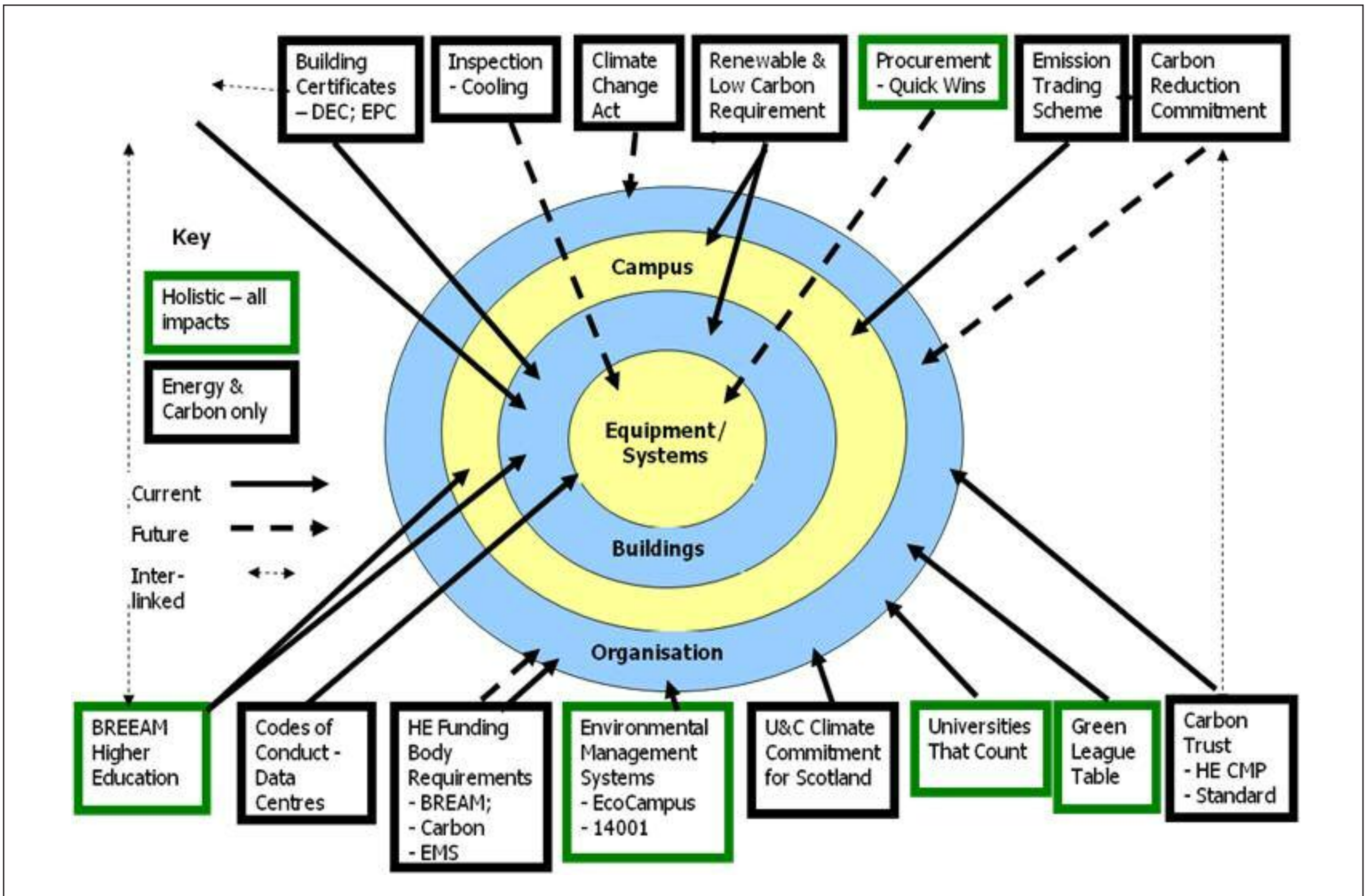

Figure 3. Towards a greener UK Campus

reduce their energy and the next generation of new and refurbished animal research facilities will have far higher targets to meet. Changes are needed if this is to be achieved and the economic life cycle costs of animal research facilities need to be considered at design stage. Value engineering will be about reducing life cycle costs and not capital costs of projects.

Laboratory Type	Typical Practice Energy Performance (kWh/m^2)		Good Practice Energy Performance (kWh/m^2)		Best Practice Energy Performance (kWh/m^2)	
	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

Figure 4. Energy Benchmarks for Laboratories

In 2007 the Higher Education Environmental Performance Improvement (HEEPI)[3] project conducted what is the most detailed examination of laboratory energy use in the UK. 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.[a] In total, nine universities submitted data on 41 laboratories[b], 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

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.

[a] Although data from the two years is not strictly comparable, it was felt that the difference in degree days between the two years (between 4-8%) would not dramatically affect the results, based on weather alone.
[b] Four engineering/physical laboratories were added subsequently.

On one hand economic and regulatory pressures will increase to reduce energy but we will still need to meet the regulatory drivers on quality environments. A UK initiative has also been established and is developing similar guidance for the British context. It is also working with its equivalents in other European Countries, such as the German Laboratory 2020 programme, to develop an EU initiative. Labs21 UK aims to reduce these and other environmental impacts, through the sharing of best practice at events, benchmarking and other means.

How do you reduce energy?

A new consensus is forming on methods which include:

Low energy ventilation design, aimed at reducing the volume and velocity of air movements (and consequent fan energy consumption), by methods such as low pressure drop air handling systems and the use of variable air volume (VAV) fume cupboards;

Evidence-based design, which uses modelling, real rather than 'nameplate' manufacturers' data on equipment's energy use and other techniques to reduce uncertainty so that overly conservative rules of thumb and safety margins can be avoided;

Crucial to laboratory energy and safety performance are more integrated and engineering-led designs, to overcome current problems of fragmented decisions by specialists and a lack of understanding amongst some professionals that heating, ventilation and air conditioning (HVAC) decisions are crucial to laboratory energy and safety performance. These need to be prominent from the earliest stages;

Clear sustainability goals, such as target air change rates or energy consumption per m^2;

Greater involvement by a range of users and facilities staff in order to improve communication within the project team and to ensure that designs are practical and effective;

More integrated and effective commissioning and evaluation so that independent quality control of this aspect exists from the start of the design process;

Value engineering to minimise whole-life, rather than first costs. To ensure that removing one element does not because of the interconnectedness of laboratory systems, have unexpected and costly knock-on effects elsewhere.

Type of Laboratory	Best	Good	Typical
Medical/Biosciences	£163,802	£234,671	£326,766
Physical/Engineering	£58,229	£97,626	£140,729
Chemistry	£151,159	Insufficient data	£292,062

Figure 5. Annual energy costs associated with a hypothetical 7,000m^2 laboratory building

[1] Based on prices of 3.14p/kWh for gas and 11.89p/kWh for electricity, energy prices have increased since this survey.

Objective data on ACH

Laboratories and animal research facilities typically consume large amounts of energy and have high carbon emissions[4] because of the large volumes of outside air utilised in ventilating them. Animal research facilities do not recirculate air but use total fresh air.

Unfortunately, little objective data has been available on the environmental and energy savings impact of safely reducing and controlling air change rates in labs and animal research facilities. We attempt to address this data gap with the results of a major research study that generated a significant amount of objective data on the indoor environmental quality (IEQ) conditions of labs and animal research facilities that are using dynamic or demand-based control approaches to lower air change rates. It is important to first understand how air changes can be safely reduced in laboratories and animal research facilities. One successful approach is by dynamically varying air change rates with a demand-based concept that uses the air quality level or "air cleanliness" of the laboratory or animal room to control its air changes or minimum dilution ventilation airflow. In a majority of laboratories and animal research facilities, the airflow is often dictated by the minimum air change rate for the space, which might be up to 12 air changes per hour (ach) in a lab room or up to 20 ach in an animal research facility. Although other factors can drive rooms' airflow such as high thermal loads or the heavy use of fume hoods or high density animal racks, it is generally the minimum ventilation rate that determines the airflow.[5]

The effect of ach on chemical spills

In research laboratories, increased airflow rates generate a significantly greater impact on clearing a room after a chemical vapour release, at least for airflow rates below about 15 ach. For example, one recent Computational Fluid Dynamics (CFD) study presented at the 2009 ASHRAE Winter Conference showed a greater than 10:1 reduction in lab room background concentrations resulted from increasing the air change rate in a laboratory from 4 ach to 8 ach.[6] Another study[5] at Yale University (where laboratory spills were performed with room air change rates from 6 to 16 ach) similarly concluded that, 'The greatest relative improvements in room air quality (both in chemical concentration and clearance time) occurred between about 6 and 8 ach, with diminishing returns beyond about 12 ach...' This information supports the contention that lowering a fixed minimum air change rate to save energy from, for example, 8 ach to 4 ach or even to 6 ach, can have a significant impact on the efficacy of clearing the lab room air of contaminants and may not be a prudent approach for many labs.

Turn down in unoccupied laboratories

Another approach that has been proposed to save energy in laboratories with respect to lowering air change rates is to reduce the minimum air change rate during night-time or unoccupied periods in procedural areas. The reasoning behind this is that if no one is in the laboratory then it is less likely to have vapours in the air. Additionally, even if vapours are in the air, no one will be in the room to be exposed. However, there are potential issues with this reasoning. First, chemicals typically are stored in the laboratory and operations are conducted 24 hours a day in hoods or even on the bench top using various equipment and apparatus that may emit contaminants at any time. Additionally, the reasoning behind unoccupied time's equating to no personal exposure has potential problems as well. For example, occupancy sensors can be used to detect when someone returns to the procedure room to immediately increase the air change rate. However, even when increasing room airflow to an occupied air change rate, a laboratory with typical ventilation effectiveness and air distribution can still take over an hour or more to significantly reduce the ambient contaminant levels. As a result, during this initial occupancy time the occupant will be exposed to potential air contaminants.[8]

Demand based ventilation control

A different approach to saving energy in labs which solves these aforementioned problems and has been shown to effectively and safely reduce air change rates in laboratories and animal research facilities is a demand based approach. This directly senses the quality of the air for such contaminants as volatile organic compounds (VOCs), ammonia, other sensed chemical vapours and particulates.[9] When the level of contaminants sensed in the room air is below a given threshold, indicative as noted below of 'clean' conditions, and then the air change rate in a room can be reduced. In other words, when the air quality is already very good, there is no reason to dilute clean air with more clean air. Additionally, even if there is occasionally an undetectable contaminant in the air, however, since the vast majority of commonly present contaminants are sensed, this concept will still deliver, on average, greater dilution air to the lab when contaminants are present.

This demand-based approach to dilution ventilation typically operates with a variable air volume lab airflow control system set to a low minimum airflow of between 2 to 4 ach. The control system typically overrides this low minimum flow based on fume hood makeup air requirements, cooling load requirements or the previously mentioned IEQ-based minimum ventilation override signal.

Demand ventilation systems are not suitable for containment level 3 & 4 facilities since particle levels in these areas cannot be measured because it is not allowed to transport particles outside the Level 3 or 4 containment rooms. However, Demand Based Control is still very suitable for the support areas and level 1 & 2 lab areas that are typically present in large numbers in these facilities.

The contaminant thresholds at which the dilution ventilation rate begins increasing and the levels to which the ventilation are commanded can be set based on the particular requirements of the lab. However, typical values for a total VOC (TVOC) threshold are about 0.2 ppm based on using a PID or photo-ionization detector type of TVOC sensor. The basis for this 0.2 ppm minimum threshold level is that it is approximately the average limit value for the LEED-NC (New Construction)

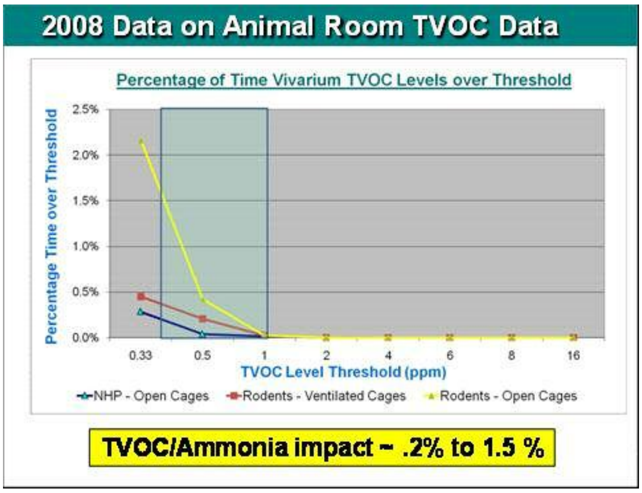

Figure 6. Graph showing Total Volatile Organic Compounds

Methodology of the study and data analysis

To get a broader view of the efficacy of this concept across not just one but many facilities, a comprehensive research study was undertaken to analyze the archived data from many different lab and animal research facility sites.

This study was conducted using environmental data from 18 different lab and animal research facility sites across the U.S. and Canada. Of these sites, six were from the East Coast, seven from the Central U.S., three from the West Coast, and two from Canada. These sites consisted primarily of life sciences and biology-related areas, as well as a smaller amount of chemistry and physical sciences lab areas. Three of the above sites involved animal facilities that formed a separate group. Almost all of the laboratories involved spaces with a moderate or low density of fume hoods. In total, more than 300 laboratory and animal research facility rooms were involved in the study, representing a large cross-section of different environments.

Approximately 1.5 million operating hours of laboratory data and about 100,000 hours of animal research facility data were analyzed. The data from the various sites was for different lengths of time depending on when the site came online. Data was analysed for laboratory operation in a range starting in the early autumn of 2006 and continuing until early January 2009. In total, more than 20 million sensor values were collected and analysed including data on TVOCs, particles of a size range of 0.3 to 2.5 microns, carbon dioxide and dew point (absolute humidity). This paper will focus only on the data collected on TVOCs and particulates since this data is most directly related to the demand-based control of air change rates.

For particles and TVOCs, most measurements were taken as differential measurements of the room conditions compared to the environmental conditions of the supply air feeding the laboratory or animal research facilities. This was done to significantly reduce potential effects of any sensor drift, as well as to allow for any impact of the outdoor conditions on the measured room conditions. Since all measurements were taken using a multiplexed sensing system, the measurements of the room conditions and the supply air feeding these rooms were taken with the same sensor, thereby creating very accurate differential measurements.

To simplify the analysis, all sensor data was placed into bins representing the number of counts or times that a parameter exceeded a specific threshold level corresponding to that bin. The data was then normalized based on the total number of data points or counts to generate the percent of time the data exceeded the bin value thresholds. A cumulative graph was created showing the percent of time that each bin value was exceeded.

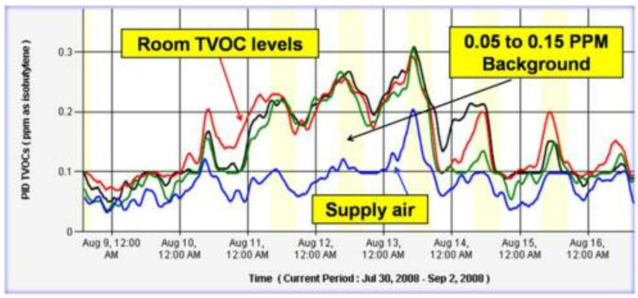

Figure 7. Showing background in room with open cages

Discussion

The largest and most comprehensive study to date on the impact of demand based control of air change rates on laboratory and animal research facility IEQ conditions and energy savings was completed in January 2009. This study involved about 1.6 million operating hours of recorded data representing more than 20 million sensor values from more than 300 laboratory spaces and 18 sites. For laboratories, on average, the IEQ conditions of low TVOCs and low particulates permitted the substantial reduction of minimum air change rates approximately 99% of the time.

Across the sites reviewed, the average laboratory room saw about 1.5 hours a week of IEQ conditions that required increasing the room airflow from its minimum value. There was some significant variability across sites with the worst-case sites for TVOCs and particles having about three times the average of all the sites. As such, the worst-case sites saw conditions requiring increased flow on average of about four hours a week per each lab room.

For the three types of animal research facilities studied similar to labs, the IEQ conditions of low TVOC and particulate levels occurred about 98.5% of the time or less, safely allowing for substantial energy savings for all but about 2.5 hours a week when higher flows were required.

With the current challenges many organizations are facing concerning reducing their carbon footprint and their use of energy, this study provides ample evidence of the significant contribution that the demand-based variation of laboratory and animal research facility air change rates can make towards safely meeting these goals.

The animal research facilities had reduced flow rates which varied between 6 and 10 ach when the rooms were sensed to be clean and the commanded purge rates, when significant contaminants were sensed, varied between 15 and 20 ach.

Conclusions

In the introduction two fundamental questions were raised:

Firstly, 'how achievable are energy reduction targets in animal facilities?' The study provides evidence of how energy reduction targets can be achieved.

Secondly, 'can Laboratory Animal Facilities cut their energy consumption to meet targets and still maintain high quality environment'? The following approaches detail how quality can be maintained:

Design – that will have a greater integration of sub-systems and more effective implementation and quality control.

Architectural principles – that will place greater weight on engineering and energy considerations and adopt more flexible and modular configurations.

Engineering principles – which will seek a greater understanding of energy loads; have more adjustable means of matching supply with demand, and 'right size' equipment to closely match actual needs.

Regulatory – that accepts evidence based design approach.

Operational – new systems that maintain quality environment but reflect the quality of air. This will result in high use rooms have more inputs and energy automatically and empty or low use rooms running at the agreed minimum level.

Value engineering – the next generation of value engineering will be focused in minimising whole-life, rather than first costs. To ensure that removing one element does not because of the interconnectedness of laboratory systems, have unexpected and costly knock-on effects elsewhere. Allowing the next generation of animal research facilities to meet energy reduction targets.

Over the next decade increasing pressure both financially and environmentally will be placed on research institutions to maintain the environmental quality of animal research facilities but reduce the energy inputs and operational costs. Illustration 4 energy benchmarks from HEEPI shows the large difference between best practice and typical which equates into far higher running costs.

Acknowledgements

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References

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