“The case for Voltage Optimisation in NHS sites”

NHS East Midlands Carbon Reduction Project Phase II

Report on the Voltage Optimisation (VO) element of the ‘Energy in NHS Estates’ pilot (1c) – Final Report

NEP, 2012

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NOTTINGHAM ENERGY PARTNERSHIP

NHS Nottingham City

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Contents

Please note that significant observations, conclusions and recommendations are highlighted in bold text throughout this report.

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1. Executive Summary

Voltage Optimisation (VO) has had a great deal of publicity as an almost universally applicable solution to energy saving. The technology can be effective in reducing energy costs and energy related carbon emissions.

However, like any technology promoted as a potential panacea, sales claims need to be rigorously evaluated to ensure that apparent savings are practical and then realised.

Through this short work focussed on three sites, we have endeavoured to assess both the energy saving claims of VO suppliers as well as the potential wider implications, including the health and wellbeing impacts of VO use within a healthcare setting. Buildings are not just energy consumers, they are work places and serve essential functions including enabling the delivery of healthcare.

One key finding of this work is that it is very difficult to quantitatively assess the actual carbon savings associated with VO, as there are potential secondary impacts on all building services and functions when considering a systemic change to the character of a buildings power supply.

Voltage alteration, even where it is successful in reducing power consumption, can have both positive and negative impacts on building services, functions and building users. Negative impacts may be possible to ameliorate, however the additional costs and inconvenience should be factored into a VO project.

To assess the potential energy savings an assessment tool has been developed to support estates teams, **'Simple VO Assessment Tool'** or **S-VAT.**

An essential observation is that VO can only save energy and money on selected equipment. Much newer equipment already has compensation built in to increase efficiency that negates the benefits of VO. While it may appear that a site will make substantial savings from VO, if in the next year significant elements of older plant and equipment are upgraded, the initially enticing savings from VO will evaporate. VO must therefore be considered in the context of the whole building backlog maintenance and replacement schedule.

Identifying which building elements are most likely to benefit from VO, and ascertaining whether they are likely to be replaced soon anyway, will help to ensure that VO is only installed where it will actually be of use.

S-VAT shows fairly consistent results with VO sales pitches. In some cases however, the savings predicted by S-VAT appear to be significant. While the initial rate of return appears quite promising, this can be expected to reduce over time as older lighting and plant are refurbished, which makes the rate of return on VO hard to predict, but it is likely to be significantly lower than the S-VAT predicts.

Another critical consideration is that of unintended consequences. Any unintended consequences for the heating and ventilation systems are hard to asses. As these are both difficult to model and measure, there is some risk that while electricity may be seen to be saved, in a holistic sense the performance of the sites mechanical and electrical (M&E) services will be degraded, and some further risk that these changes will never be detected.

From our analysis we have developed a list of key systemic effects of VO which should be risk assessed and valued as part of the business case.

- **Dimming of lighting and any health and safety and psychological implications** this may have.

- **Reduced ventilation and indoor air quality from slower operation of fans.**
    - Health and wellbeing impacts of potentially increased carbon dioxide levels and any impacts this may have on ability to concentrate and mood. This could be of increased importance in an acute or mental health setting.
    - Health and wellbeing impacts of potentially increased airborne pathogen levels.

- **Reduced central heating circulation from impacts on pumps.**
    - Less even heat distribution. This could effect thermal comfort and how building users then interact with control systems. This could potentially lead to unexpected increases in heating fuel use or cooling power.
    - Lower return temperatures causing boilers to fire more of the time, again increasing heating fuel consumption.

- **Reduced electric heating capability.**
    - Reduced hot water production.
    - Possible clinical issues arising from time to sterilise / autoclave equipment.

A simple representation of the last point would be the fact that a kettle in a lower voltage work place would take longer to boil. The associated additional costs through loss of productivity in staff time waiting for the kettle to boil would not be a natural consideration of the potential financial impacts of VO.

Given the above comments about the lighting and pump / fan loads, and the lack of information about the systemic effects of varying the pump speed on heat distribution, there seems to be insufficient certainty to build a robust business case for the deployment of VO which will guarantee good cost, energy and carbon savings, despite the simple payback calculations that have been performed.

Although VO may demonstrably reduce electricity consumption and the costs and carbon emissions that arise from this directly, care should be taken to establish that total carbon emissions and costs are not increased because of other changes such as in the behaviour of the central heating system.

Of the three sites that expressed interest in this project, only one (Wells Road) has installed VO equipment, and this in turn has given rise to problems, particularly with regards to the lift system. This has necessitated the fitting of a step-up auto transformer to power the lift from the new 'optimised' site voltage, adding to costs and making monitoring of savings difficult.

2. Project overview

In 2009/10, the East Midlands NHS Carbon Reduction Project (EM NHS CRP) was established. Funded by the NHS East Midlands Regional Innovation Fund, this Project consisted of two distinct phases:

PHASE I:

- Phase I of the Project succeeded in **establishing the carbon footprint of the NHS in the region** which was made available to the public in a published report[1] launched at an EM NHS Sustainable Network event held in Nottingham in November 2010[2].

- The regional NHS carbon footprint identified that **27% of all CO_2e emissions** attributable to the NHS in the East Midlands arise as a result of energy use in healthcare buildings, evidencing the significance of this aspect of carbon management and the need to take urgent action to minimise it wherever possible.

- A series of **strategic and practical recommendations** stemmed from the Phase I report, to support improvements in natural resource efficiency and reduce the environmental impact of healthcare provision in the region.

- These recommendations concentrated on measures which could be **seamlessly and easily integrated** into the daily operations of NHS trusts and other healthcare organisations ranging from the 'tried-and-tested' to the cutting-edge of innovation and covered potential savings across energy, cost and carbon emissions.

- As a result, **six pilot projects** were developed as a means of putting some of the Phase I key recommendations into practice, led by a range of specialist providers working in partnership with healthcare organisations across the region.

PHASE II:

- In March 2011, NEPes were commissioned by the East Midlands NHS Sustainable Development Network to **deliver the 'Energy in Estates' Phase II pilot**.

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[1] NEP, 2010. *"NHS East Midlands Carbon Reduction Project Phase I – Report on Footprinting, Analysis and Recommendations".* Available at: http://www.tin.nhs.uk/innovation-nhs-east-midlands/innovation-in-practice/regional-innovation-fund-projects-2009-10/identifying-and-reducing-the-regional-carbon-footprint-of-the-nhs-in-the-east-midlands/?locale=en?

[2] 'Fit for the Future? A Low Carbon Health Service Conference and Marketplace'. 18/11/10, Nottingham Conference Centre. For more information please visit: http://www.emphasisnetwork.org.uk/networks/sd/event18nov10.htm

- To date, this pilot has effectively supported a number of healthcare organisations with the assessment and integration of **sustainable energy technologies** across a range of buildings and different healthcare settings throughout the region.

- The **types of technology** covered by the pilot, which have also determined its distinct **delivery strands**, have been:

    a) Smart metering,

    b) **Voltage optimisation,** which is the focus of this report, and

    c) Renewable Energy Assessment (REA).

- The key aim of the VO element of the pilot was to provide support to three healthcare organisations from across the region to ensure that they identified and wherever possible, realised the full benefits derived from installing Voltage Optimisation solutions in their buildings.

- This overall aim was designed to be met through preparation of the business case with three trusts for installation of voltage optimisers.

- In order to measure the pilot's success in meeting the above objectives, **six key performance indicators (KPIs) were agreed**. These KPIs are featured in full in Table 1.

- Despite the mostly quantitative nature of the pilot's KPIs, **both quantitative and qualitative data** from primary and secondary sources have been collated, analysed and monitored throughout the pilot, to ensure that its recommendations are replicable, practical and understandable to those who may take them forward.

- Overall, the **VO element of the pilot has not succeeded in meeting the KPI objectives as set out** set against its delivery as summarised in Table 1, however the project has revealed a number of key issues with VO that required consideration and developed a self assessment tool for site managers to estimate their own potential for savings.

Table 1: Summary of performance against the EM CRP Phase II REA pilot Key Performance Indicators (KPIs) *(Source: NEP, 2012).*

KEY PERFORMANCE INDICATOR (KPI)	**PERFORMANCE TO DATE** (21/02/12)
1. Number of Trusts involved in VO in this pilot.	**3 trusts** were engaged with as pilot partners and supported throughout this pilot strand: Derbyshire Community Healthcare Services (DCHS), Leicestershire Partnership Trust (LPT), and Nottinghamshire Healthcare NHS Trust (NHT).
2. From involved trusts, number of VO units/ interventions undertaken or likely to be undertaken within next 12mths	DCHS: **1x site** investigated (Ilkeston Community Hospital). Possible installation if business case was strong enough. NHT: **2x units** installed and working (Wells Road Centre and Duncan MacMillan House). One more installed (Wathwood Hospital) but not operational due to technical issues. LPT: **1x site** investigated (Bradgate Unit). Possible installation elsewhere if business case was strong enough.
3. Energy consumption (kWh) covered by VO interventions or interventions likely within next 12 months.	DCHS, Ilkeston Community Hospital **– 1,277,791kWh** NHT: • Wells Road Centre – **1,063,009 kWh** • Duncan Macmillan House – **1,422,870 kWh** • Wathwood Hospital – **717,572 kWh** All 3 NHT installations are now in place; however, they were not being fully utilised due to technical issues. Support from this pilot has enabled some of these issues to be overcome, so that these sites could begin to realise the benefits of VO.
4. % of Trusts' electricity consumption to be covered by VO.	DCHS, Ilkeston Community Hospital – **4%** Nottinghamshire Healthcare Trust (NHT) – **18.4%** overall, details are given below: • Wells Road Centre **– 6.1%** • Duncan Macmillan House **– 8.2%** • Wathwood Hospital **– 4.1%**
5. Projected annual energy +carbon saving from above VO, supplier and independent.	Not possible to project independently with full certainty, given that site-wide holistic effects may well undermine any projected carbon savings from voltage reduction and future equipment upgrades may degrade projected carbon savings. Independent analysis has estimated the following: • DCHS, Ilkeston Community Hospital: Suitable for VO. **5%** annual energy saving (**68 MWh**), equating **39 tCO_2e** saved annually. • NHT, Wells Road Centre (only the Wells Road Centre was assessed and verified for potential savings): Marginal case for VO, better data pre-and-post install would be beneficial. **~5.5%** annual energy saving (**58MWh**), equating **33 tCO_2e** saved annually. • LPT, Bradgate Unit- - Unsuitable for VO. **~2%** annual energy saving (**14.278** MWh), equating **8.138 tCO_2e** saved annually.
6. Payback period and IRR for investment in each case.	Paybacks estimated as follows: • DCHS, Ilkeston CH: **~5 years;** NHT, Wells Road Centre: **~8 years;** LPT, Bradgate Unit: **~13 years.** IRR not calculated as there are too many unknowns factors to give any clear and meaningful figure on Internal Rate of Return in the cases studied.

2.1 Data, information sources and assumptions made

ENERGY CALCULATIONS INCLUDING SAVINGS:

- Once engaged in the pilot, each partner organisation was advised on how to best put forward a selection of their sites for VO assessment. This support was carried out via telephone, email and in person communications by NEPes. The data provided by each partner organisation included site name and full address if VO systems were already installed on-site and wherever possible, total annual site energy demand/use.

- Sites were visited by an engineer and potential was assessed along with an interview with estates and energy management staff about experiences to date with VO, including any previous experience of VO assessment by VO sales staff.

- Potential energy savings from VO were calculated using information from engineer surveys and the S-VAT excel tool developed to support this project.

CARBON CALCULATIONS INCLUDING SAVINGS:

- All carbon emission savings were assumed to be a direct result of reducing site grid-electricity voltage.

- All carbon emission savings were calculated using national best practice carbon accounting methodologies based on the Greenhouse Gas Protocol, informed by the latest DEFRA guidance. Carbon emissions factors where applied to potential electricity saving from the 2011 Guidelines to DEFRA Greenhouse Gas Conversion Factors for Company Reporting [3].

Electricity *(2009 5-year Grid Rolling Average):* **0.59368 kgCO_2e per kWh**

- Consideration of the total social cost of carbon, measured in £22.4 per tCO_2e, was also given in each assessment[4].

FINANCIAL CALCULATIONS INCLUDING SAVINGS:

- Financial calculations on the potential annual savings from utility bills and likely payback periods were modelled.

- In order to calculate the potential cost reduction from electricity bills as a result of VO the following assumptions have been made:

Supplied electricity price (ppkWh): **10 / £0.10***

**10ppkWh is a typical cost per unit of supplied electricity in the NHS.*

[3] www.defra.gov.uk/environment/economy/business-efficiency/reporting/
[4] http://www.hm-treasury.gov.uk/d/scc.pdf and http://www.decc.gov.uk/publications/basket.aspx?filetype=4&filepath=11%2fcutting-emissions%2fcarbon-valuation%2f3136-guide-carbon-valuation-methodology.pdf&minwidth=true#basket

2.2 Action learning approach

Action learning is a process which involves working on real challenges, using the knowledge and skills of a small group of people combined with skilled questioning, to re-interpret old and familiar concepts and produce fresh ideas[5].

As agreed at the start of Phase II of the EM NHS CRP, an action learning approach was employed throughout the delivery of this pilot, to ensure that its outcomes would be directly informed by real-life examples and lessons from the ground, making them truly pragmatic and replicable.

This approach is evidenced as follows:

- Early discussions with the East Midlands NHS Sustainable Development Network[6] informed the project's preliminary steps in terms of confirming the direction, scope, and format of delivery.

- An informative 2-page project overview brochure (see Appendix 1) was produced and disseminated widely throughout the region to promote the project's key aims and to help engage relevant members of the local health community. This was accompanied by a brief form (see Appendix 2), to enable the collation of baseline data from each of the potential partners.

- With the help of the Network's publicity and the circulation of the two documents mentioned above, all pilot partners were identified early on so that support provision would be prioritised effectively and successfully.

- All pilot partners were kept closely informed and engaged throughout the pilot's duration via email, telephone and in person communications.

- The thoughts, feedback and personal experience of all participating organisations were pro-actively sought throughout. In this way, partners often made valuable contributions which helped to tailor both the support provided throughout the pilot and the development of resources to be disseminated thereafter. The development of the S-VAT tool is an example of the latter.

- The difficulties in creating general conclusions from sites data have meant that the site surveys and modelled data have had to suffice in terms of assessed impacts on electricity savings. Site by site surveys and conversations with key staff however, have revealed potential opportunities and weaknesses in VO that are useful and replicable for other estates and energy managers.

"The end of learning is action, not knowledge".
Peter Honey

[5] http://www.actionlearningassociates.co.uk/actionlearning.html
[6] Such as those held during the EM NHS CRP Phase II Workshop, 15/06/11, Nottingham. Details available at: http://www.emphasisnetwork.org.uk/networks/sd/event15june2011.htm

Health and wellbeing benefits

Every 24 hours, 1.3 million NHS employees use thousands of buildings in hundreds of health centres, surgeries and hospitals nationwide to see and treat nearly one million patients[7]. By doing so, healthcare buildings in England consume over £410 million worth of energy annually. This use of energy constitutes an increasingly important area of spend for the NHS. It is also responsible for significantly contributing to climate change through release of 3.8 million tonnes of CO_2e annually.

The latter is of crucial importance as climate change has been identified as the biggest threat to global health[8]. Its effects on the health and wellbeing of the general population are already being experienced on a widespread scale as a result of the increased occurrence of extreme weather events such as flooding and heat waves, and over the coming decades, will put millions of lives at risk.

The steep rise in market energy prices, coupled with the current economic recession, only add to the above threats by increasing the risk of people falling into fuel poverty which is evidenced to have serious detrimental impacts on public and mental health.

> **"Investing in the energy efficiency and resilience of the estate is particularly important in view of the current supply climate, escalating fuel costs and the potential impact of 'peak oil'. Switching to low carbon forms of energy, such as renewables helps to guarantee supply and reduce the carbon footprint of the estate".**
>
> *NHS Sustainable Development Unit.*

VO as a technology is sold as a potentially low cost, high impact route to carbon savings that could, if as effective as suggested, in turn have significant health and wellbeing impacts through mitigated climate change.

VO, when put into practice could in theory minimise the NHS contribution to climate change, help organisations to become more energy cost-resilient, and support the enhancement of the health and wellbeing of society in and beyond the East Midlands.

Conversely we have also found that there may be less obvious negative health and wellbeing impacts of VO that may have unforeseen impacts on the holistic carbon footprint of a building through potential unforeseen impacts on other areas of emissions, such as heating fuel or cooling requirements. Without consideration being given to adjusted lighting levels, water heating implications, pump speeds and impact on air circulation and ventilation from fan speeds there are a whole host of potential low grade negative health and wellbeing implications.

There are some considerations that are particularly relevant to a clinical environment such as light levels in diagnostic areas, impacts of higher CO2 concentrations from reduced ventilation on staff and patient mood and wellbeing, thermal comfort, lower ventilation levels and impacts on air borne pathogen levels, slower heating of hot water and potential implications for pathogen destruction.

[7] http://www.sdu.nhs.uk/documents/publications/1234888949_zfGK_energy_and_carbon_management.pdf
[8] http://www.thelancet.com/climate-change

2.3 Methodology

While the project was designed with the intention of pre and post install metering, because of the type of participants engaged, the methodology had to be amended. Hospitals have a varying demand for energy, depending on the number of patients and the season, after initiation of the project a simple comparison of energy consumption before and after VO installation it was decided not likely to offer meaningful data.

Even a CUSUM analysis would be difficult to interpret if no period of stable energy consumption can be identified prior to VO installation, and many factors which contribute to energy use are changed in a short time frame.

This situation is further exacerbated during periods of refurbishment.

Because the prediction of the benefit arising from VO is not a simple process, we have proposed that the benefit be assessed empirically at a number of sites. We have suggested that once VO has been installed, it be run normally and bypassed on alternate weeks. Logged data, or hourly utility data would then be used to assess the effect of switching the VO in and out, using an appropriate statistical method to remove noise from the data collected.

Of the three sites that expressed interest in this project, only one (Wells Road) has installed VO equipment, and this in turn has given rise to problems, particularly re the lift system. This has necessitated the fitting of a step-up auto transformer to power the lift from the new 'optimised' site voltage, but the presence of this step-up transformer makes switching the VO in and out on an ad hoc basis difficult. A fourth site has however provided some pre and post installation data for reference.

On sites where the loads do not preclude switching the supply through the VO system or putting it on bypass, ease of switching might be a consideration when purchasing. It is, for example, our understanding that Power Perfector requires manual switching off of the optimised feed, followed by the switching on of the bypass. The potential for error, and the possible cost may result in switching being regarded as onerous and risky, and the brief interruption to supply is obviously undesirable. Furthermore, the switch on surge current as equipment restarts, makes simple 'a second before, a second after' comparisons impossible to make.

By contrast, PowerStar marketing literature states that bypass can be achieved by a single switching operation, and that the drop in energy consumption is immediately visible. If true, this ease of demonstrating benefit is of significant value in establishing that VO has a significant benefit.

Further problems with switching VO in and out arise from concerns expressed by the IT Operations, that this poses a risk to the Trusts central servers and concerns have also been expressed re the triggering of UPS and backup generator systems.

These factors have prevented the collection of data from a live VO system to date, though it is hoped that it may still be possible to undertake these measurements in the future.

3. An Introduction to Voltage Optimisation Issues

This work has been undertaken in association with three Trusts which were, or are, considering Voltage Optimisation (VO).

It details issues which might be considered by these, and other Trusts, some of the lessons learned about VO, and how easy it is to assess the benefits and problems which might arise.

Voltage Optimisation, is by its nature a fairly technical topic. To grasp the arguments around Voltage Optimisation (VO) issues, it is important to be familiar with the basics of Ohm's Law and the calculation of the power consumption of electrical loads.

This work then is primarily intended to support facilities managers and other staff involved in the technical aspects of procurement decisions, though we hope other staff may still gain some insight into the complexity of VO issues and their assessment.

While VO sales literature makes much of the benefits of improved power factor and harmonics, the core of the argument for the deployment of VO is generally cost and carbon savings arising from a reduction in energy consumption. It is perhaps then appropriate to start with the core issues of electrical power, energy consumption and energy cost.

3.3. Basic Electrical Theory and Electricity Charges

3.3.1. Energy, Power, Voltage and Current

All useful electrical appliances perform an operation or service by the use of electrical energy.
The amount of electrical energy used is metered by the supplier and the consumer is charged accordingly.

Electrical energy is normally measured in kilowatt hours (kWh). A kilowatt hour will have been consumed when an appliance using a power of a kilowatt (kW) has run for an hour or an appliance using two kilowatts has been run for half an hour etc.
A kilowatt indicates a power consumption of a thousand watts (W). To give some examples, a low energy light bulb might have a power consumption of nine to twenty watts, a single bar electric fire might have a power consumption of a kilowatt, and a large electric motor in an air condition system might be rated at twenty to fifty kilowatts.

The amount of power in watts, used by an appliance, can be calculated by measuring the electric current that passes through it, and the voltage applied to it. Electric current, measured in amps (A), gives an indication of the number of electrons moving round an electrical circuit. The voltage (V) indicates the electrical 'potential difference' or 'electric tension' that drives the current through the appliance. The power is calculated by multiplying the current passed by the applied voltage.

For example:

1 kWh = 1,000 Wh = 1,000 W used for one hour

1,000 W = 250 V X 4 A or 220V X 4.55A etc…

3.3.2. Resistance

Resistance limits the flow of current in a circuit. In general, the more voltage is applied to a circuit, the more current it will pass, and the higher the resistance, the less current it will pass.

Resistance is measured in ohms (Ω). For a given fixed resistance, the higher the voltage, the higher the current.

For a ***simple resistor*** whose resistance remains fixed with variations of applied voltage and current, the following will be true.

$A = V / \Omega$ $\Omega = V / A$ $V = A\,\Omega$

These relationships are known as Ohm's Law.

As W = A V,

$W = A^2\,\Omega$ $W = V^2 / \Omega$

Given that

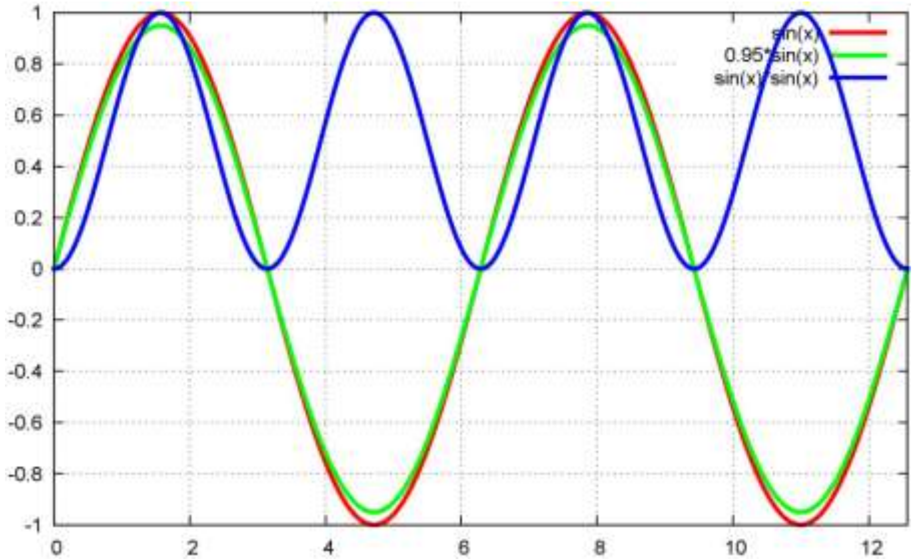
$W = V^2 / \Omega$

As the voltage term is squared, it can be seen that for a ***simple linear resistor***, a small change in the applied voltage will result in a large change in the power, and therefore in the energy used over time.

3.3.3. Power Factor Technicalities

Readers who are not interested in the technicalities of power factors may choose to skip to the next section.

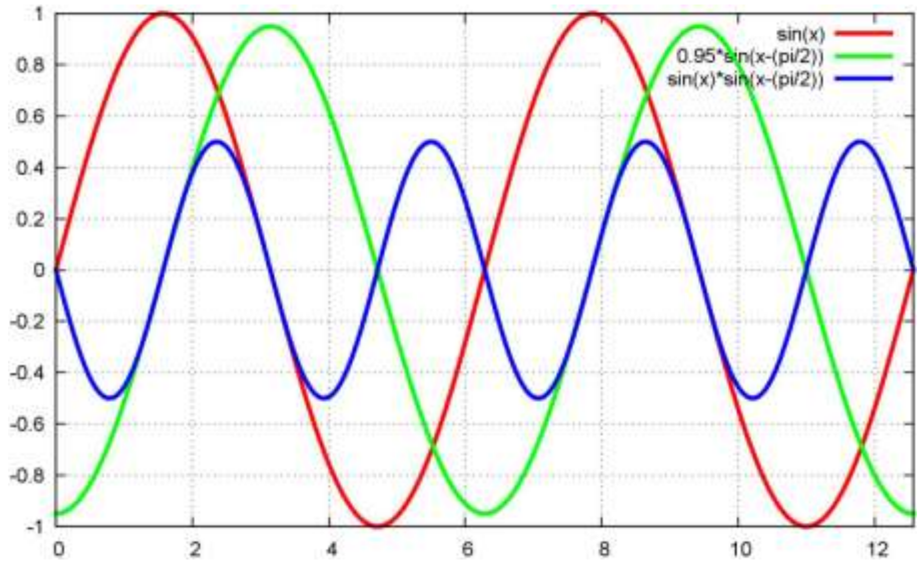
Grid powered equipment is run from an alternating current (AC) supply, which applies a sine wave voltage to the load. For a simple resistive load such as an immersion heater, the voltage and current are both sine waves, and the power dissipated in the load is the product of the voltage and current.



In the above diagram, the red sine wave represents the applied alternating voltage, and the green represents the resulting alternating current flow. The blue line represents the energy transferred to the load. As the wiring that carries current to the load also has a small resistance, inevitably some energy will also be transferred to this which will slightly raise its temperature.
For a simple resistive load, the voltage and current waves are synchronised, crossing zero at the same time, and reaching their maximum values at the same time. These are said to be 'in phase' with a power factor of 1.

Voltage and current are not always in phase. The current can be advanced or retarded with respect to the voltage. This timing difference can be expressed in degrees or radians, and the power factor is an expression of the 'phase angle' between the voltage and current waveforms, and is expressed as the cosine of that angle which is normally written as 'cos ϕ'.

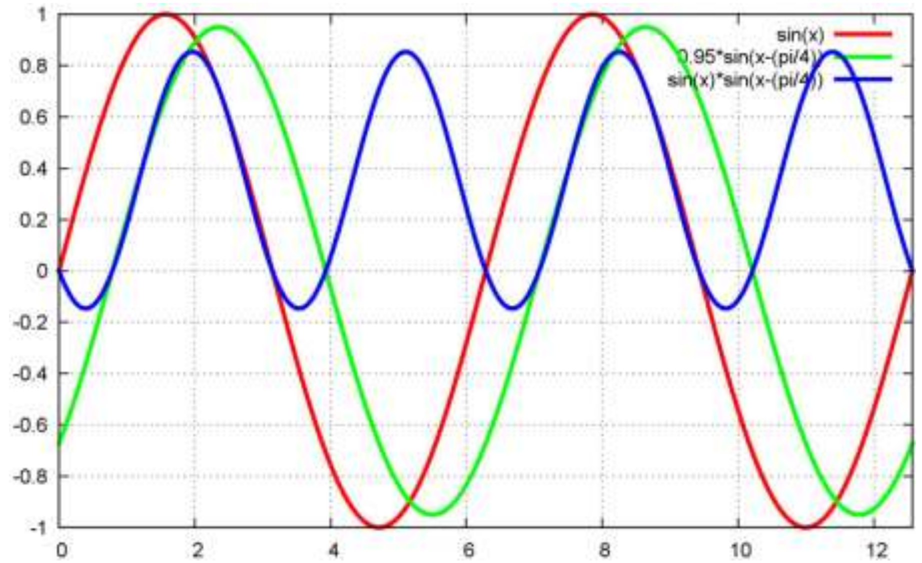
Electrical loads which are not simple resistances can advance or retard the current wave with respect to the voltage wave, and are described as reactive. There are characterised by having some capacity to store energy. In extremis, all the energy can be transferred into the load and back out again, giving rise to the set of curves shown at the top of the next page.
Note that as much energy leaves the load as enters it, so there is no net transfer of energy to the load, but a current still passes, even though no productive work is being done. This is described as a power factor of 0.



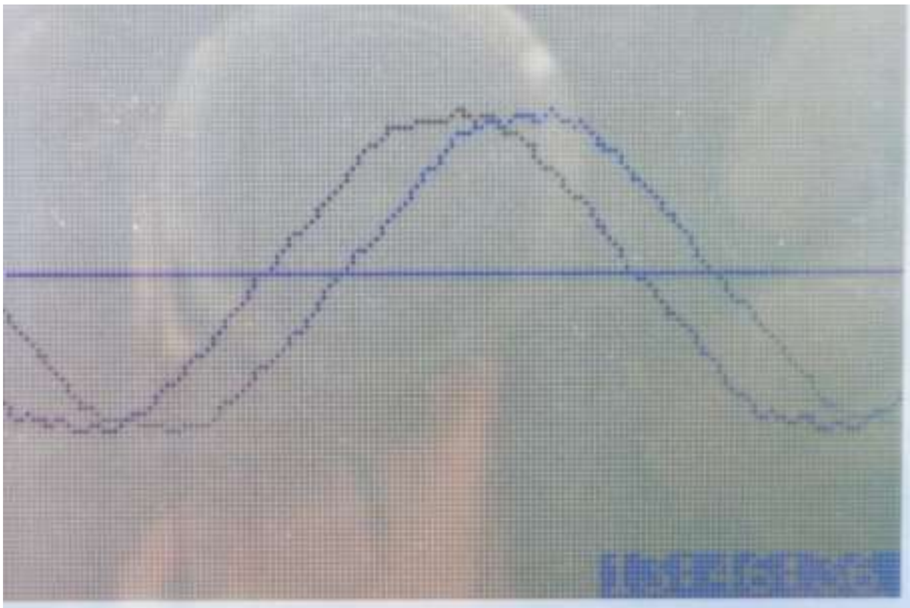
Again, as the wiring that carries current to the load also has a small resistance throughout the building and the national grid, some energy will be transferred to this, wasting energy by heating the cables, even though the load is doing no productive work. This is obviously undesirable from efficiency and environmental points of view, and consumers may be financially penalised if their power factor is too low.

3.3.4. Power Factor Summary

Many real world loads have power factors significantly less than 1 (The higher the power factor the more efficiently the electricity distribution infrastructure is used). Examples of loads which may have poor power factors include old fluorescent lights that use a magnetic ballast and electric motors, including those in fans and pumps. As the load is reactive, but some productive work is done, curves such as the following would be typical, (voltage red, current green, and power blue).



These voltage and current curves can be seen on an oscilloscope or other instrumentation that can graph current and voltage waveforms.



Current and voltage waveforms viewed with the oscilloscope function of a power analyser and data logger for a load with a power factor, cos ϕ, *of about 0.6.*

3.3.5. Electricity Charges

Additional charges may be made by the supplier if an agreed maximum supply current is exceeded, or if the power factor deviates significantly from one, though these additional costs are usually relatively small. From resource efficiency and carbon reduction points of view, electrical loads should have power factors as close to one as possible.

The amount of these additional charges varies from one supplier to another.

On a site which is close to its maximum supply capacity, VO might help to avoid charges made for exceeding the maximum instantaneous demand identified in the supply contract, but as VO is only likely to offer a few percent reduction in power consumption, it is not likely to be the basis of a long term solution.

3.4. Assumptions and Flaws in the Assumptions

3.4.1. Assumptions

Voltage optimisation is generally sold on the basis that a small change in the applied voltage will result in a proportionately larger change in the power and therefore the amount of energy used over time. As a money saving measure this sounds promising and will be true for a ***simple linear resistor***.

Many electrical loads are not linear resistors however and the amounts of energy that can be saved vary significantly from site to site, depending on the installed plant and equipment.

3.5. Summary of Potential Advantages

The proponents of Voltage Optimisation (VO) have endorsed it on a number of grounds:

- Reduced energy consumption, cost and carbon emissions.
- Improved power factor.
- Attenuation of high voltage transients, spikes, surges, etc.
- Increased equipment life and reduced wear and tear.

3.6. Summary of Potential Disadvantages

Superficially, cost is the main barrier to the uptake of VO solutions, but there are other issues which should be considered. For example, if the power used by a circuit produces a useful outcome such as light or heat, the reduction in power if achieved can only reduce the level of illumination provided by affected lights or the amount of heat produced by electric heaters.

Other issues have been encountered where the reduced voltage has not been regarded as adequate for certain items of equipment. At Duncan Macmillan House for example, it has been necessary to install a step-up autotransformer to ensure safe lift operation now that the site wide voltage has been reduced, and at Glenfield Bradgate Mental Health Unit, it is understood that the air conditioning is likely to become inadequate should the site mains voltage be reduced.

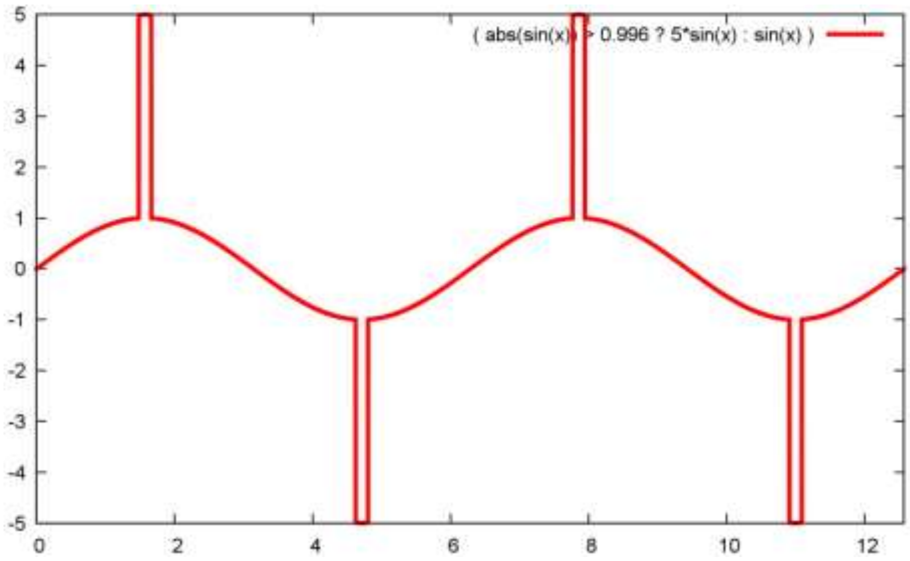
Of the three Trusts visited then, two of them have encountered technical problems where a reduced site voltage gives rise to problems and costs over and above those arising as a directly from the installation of the VO equipment itself.

It seems reasonable to expect that the larger and more complex the site on which VO is installed, the greater the probability of some items of plant or equipment being incompatible with the adjusted site voltage.

3.7. Situations in which VO will be a benefit

VO will be a benefit where the energy consumption of an appliance can be reduced without reducing the useful output, or the rate of work done by the device, or where the life of the equipment is usefully extended which reduces the need for expensive maintenance in hard to access locations, and the associated ‘down time’.

VO can particularly be of benefit on sites where motors and other electromagnetic machines are driven at too high a voltage causing magnetic saturation. When this occurs, very high currents can be drawn during the higher voltage parts of the applied sine wave, which can cause a great deal of energy to be wasted (as heat), potentially damaging the equipment. In this situation, rather than being sinusoidal, the current waveform will be something like the following.



3.8. Situations in which VO will be little benefit

Where VO reduces the useful output of a device or appliance, appliances may need to be operated for longer to do the same amount of work. Where appliances are in constant use, more appliances may be required to provide the same output, or to do the same amount of work.

The assumed benefit of VO relies on the notion that the load is a simple resistor that obeys Ohm's Law.

3.9. Some Real World Examples

The full effects of voltage optimisation are not always obvious at first sight. This section will present five simple examples.

3.9.1. Simple Example 1 - an Immersion Heater

A nominal 3kW single phase immersion heater intended UK grid use might have a resistance at its working temperature of around 19.2 Ω.

If this is powered from a 240V supply, it will pass a current of 12.5A and dissipate 3kW.

If VO reduces the supply voltage by 10% to 216V, the current falls to 11.25A, and the power dissipated falls to 2.430kW.

The power consumption falls by 19% which sounds like good news, but the following must be kept in mind:

- The time taken to raise the temperature of a given amount of water by a given number of degrees will be increased by over 23%.
- The total amount of energy required to heat the water will not be reduced by heating it more slowly. Peak instantaneous power consumption will fall, but thermostatic control will run the heater for a greater proportion of the time and energy use, energy cost and carbon emissions will be the same.
- The life of the immersion heaters might be increased but the capacity to heat large volumes of water quickly is reduced which might compromise the operation of the hospital at times of peak demand or during an emergency.

3.9.2. Simple Example 2 - Boiling a Kettle

Using a calculation similar to the above it can be seen that it will take longer to boil a kettle. If it takes longer to boil, it will be hotter than ambient temperature for longer, so losing heat to the environment for longer. Therefore, a greater proportion of the energy input is lost to the environment, so water heating efficiency must be reduced at the lower voltage.

Perhaps more significantly, expensive staff will wait longer waiting for the kettle to boil.

Calculation suggests that if we assume tap water starts at 10 degrees, a standard 1.5 litre kettle will boil in 188.41 seconds at 250V while dissipating 3kW. At 220V it will dissipate only 2.323kW, only 77% of the power, and boil in 243 seconds. That's 55 seconds longer, even ignoring increased heat losses from the kettle.

This is not more energy efficient, and potentially much less commercially efficient if you are paying three staff 66p each per minute to stand around while the kettle boils. In effect, VO might add nearly £2 to the cost of a tea break, without reducing energy costs or carbon emissions.

3.9.3. Example 3 - Fluorescent Lighting With 50Hz Magnetic Ballast

When we have experimented with Fluoresave, a product which uses a transformer to reduce the supply voltage to magnetically ballasted fluorescent lighting, we have found that to within better than 1%, the light output falls in proportion to the input power. VO is likely to have a similar effect.

This will reduce the amount of energy consumed, carbon dioxide emitted and might reduce the amount of maintenance required to change tubes, but we could discern no improvement at all in lumens per watt efficiency.

3.9.4. Example 4 - Appliances With Switch Mode Power Supplies

A switched mode power supply unit (SMPSU or SMPS) uses sophisticated electronics to allow highly efficient delivery of electrical power within an appliance and is usually used to provide one or more regulated (fixed) output voltages. Assuming the load that the SMPS drives draws a constant current when supplied with a constant output voltage, the SMPS will consume a very nearly constant power as the input voltage is varied.

When a constant power switched mode appliance is powered from the mains, the power will be the product of the supply voltage and current.

$W = V A$ (See section 4.1.1)

As W is a constant, reducing V by the use of VO must increase the current drawn. Appliance power consumption remains the same, so no energy or carbon emissions reduction is achieved.

It should be noted however, that if the current is increased in the wiring within a building, this will cause some energy loss as the cable has some resistance. The power loss in the cable is given by

$W = A^2 \Omega$ (See section 4.1.2)

where W is the heat dissipated in the cables, A is the current drawn by the load, and Ω denotes the cable resistance. For a constant power 1kW load, reducing the supply voltage from 240 to 216 volts would increase the load current from 17.36 to 21.43 amps, and the heat dissipated in the cables would increase by around 23%. This might be significant if the existing cabling is running at near its rated capacity load and this risk should be assessed.

Further to this, many switch mode power supplies operate most efficiently with higher supply voltages.

Many modern electrical fittings and appliances now use switch mode power supplies of one sort or another, and the proportion is increasing all the time. This includes most modern lighting (most LED, modern fluorescent, compact fluorescent lights, and halogen lights with solid state transformers), the vast majority of IT, communications and surveillance equipment, and motors with electronic and variable speed drives.

The increased use of switch mode power supplies is likely to erode the benefits of VO equipment within the period of time that a return on the investment might reasonably be expected. Account should be taken of this when modelling the financial outcomes.

3.9.5. Example 5 - Pumps And Fans

If a pump, fan or any other motor driven device is driven by an electronic drive, it is unlikely that the speed will be influenced by VO. If there is no electronic drive, the speed of the device may be influenced by voltage reduction and electricity consumption may be reduced.

The manufacturer of the device should be contacted however, to see if the efficiency of the device is degraded by voltage reduction, and how performance might be affected.

Even if the motor electricity consumption can be shown to be reduced by VO, it should be questioned if the amount of fluid pumped, or the amount of air blown per kWh is degraded or enhanced. If it is degraded, this raises the possibilities that;

- the performance of the system as a whole might be degraded per kWh of electricity purchased, or that;
- insufficient water would be pumped or air blown to meet the users requirement, or to comply with regulations.

For example, if pump energy consumption, speed and efficiency are reduced by VO, it should be asked how this changes the flow and distribution of heat around the building. If for example, the central heating system return temperature falls because of reduced pump speed, the boiler may fire more, but the heat that is delivered to the building may be less evenly distributed. This could result in an increase in total operating costs and carbon emissions by increasing the use of energy for space heating.

Similarly, if a fan motor energy consumption is cut by VO to save energy, will the ventilation requirements meet statutory requirements and clinical needs, and will the performance of the building per kWh be improved in a holistic sense. Risks should be assessed re increased numbers of micro-organisms in the air, and increased carbon dioxide concentrations.

3.10. Marketing Materials and Sources of Independent Information

Trusts have found few good quality independent sources of information on voltage optimisation. This is partly because the topic is complex and the information available is frequently simplistic and / or biased.

3.10.1. Marketing Materials

Information provided by the manufacturers should be evaluated critically. Re the picture on the next page for example (stuck on to an installed voltage optimisation system, presumably by the manufacturer), a number of assertions might be challenged.

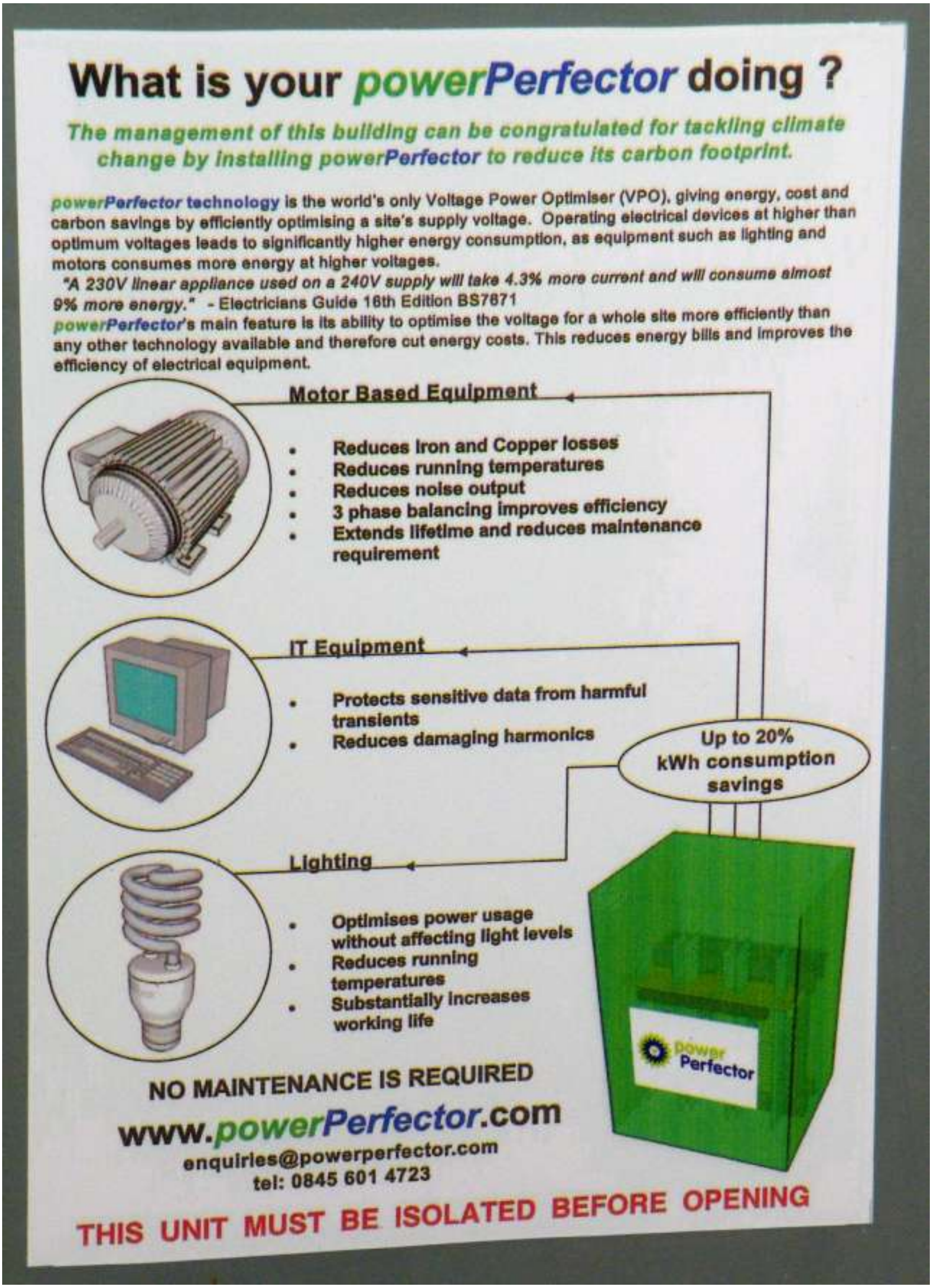
It seems likely that other manufacturers of VO equipment would argue that their products also optimised cost energy and carbon savings by VO.

General statements such as "…lighting … consumes more energy at higher voltages" should be evaluated with care as the newer the installed lighting, the less likely this is to be the case.

The statement that

> *"A 230V linear appliance used on a 240V supply will take 4.3% more current and will consume almost 9% more energy."* - Electricians Guide 16th Edition BS7671

is itself interesting. While the ratios of consumption are correct, for a simple load in continuous operation, the statement takes no account of the nature of loads such as water heaters, etc, as described above, which in reality will have their power consumption while operating reduced, but which will run for a greater portion of the time, bringing about no net energy saving. Quotes such as the above, however reputable the source, may be unhelpful if the full context is not clear to the reader.


What is your powerPerfector doing ?
The management of this building can be congratulated for tackling climate change by installing powerPerfector to reduce its carbon footprint.
powerPerfector technology is the world's only Voltage Power Optimiser (VPO), giving energy, cost and carbon savings by efficiently optimising a site's supply voltage. Operating electrical devices at higher than optimum voltages leads to significantly higher energy consumption, as equipment such as lighting and motors consumes more energy at higher voltages.
"A 230V linear appliance used on a 240V supply will take 4.3% more current and will consume almost 9% more energy." - Electricians Guide 16th Edition BS7671
powerPerfector's main feature is its ability to optimise the voltage for a whole site more efficiently than any other technology available and therefore cut energy costs. This reduces energy bills and improves the efficiency of electrical equipment.
Motor Based Equipment
• Reduces Iron and Copper losses
• Reduces running temperatures
• Reduces noise output
• 3 phase balancing improves efficiency
• Extends lifetime and reduces maintenance requirement
IT Equipment
• Protects sensitive data from harmful transients
• Reduces damaging harmonics
Up to 20% kWh consumption savings
Lighting
• Optimises power usage without affecting light levels
• Reduces running temperatures
• Substantially increases working life
power Perfector
NO MAINTENANCE IS REQUIRED
www.powerPerfector.com
enquiries@powerperfector.com
tel: 0845 601 4723
THIS UNIT MUST BE ISOLATED BEFORE OPENING

Regarding the rest of the points made on this sheet, it is certainly true that electric motors which are driven into magnetic saturation by excessive supply voltage would benefit from VO, but in other situations the benefits should be quantified with care and the consequences for systemic efficiency and safe operation considered.

Energy savings for IT equipment are likely to be minimal as these will generally use switch mode power supplies for which the power consumption is independent of supply voltage. While protection of IT equipment from transients may have some value, Trusts should consider if this is a problem that they need to spend money on or not and if they might address this issue more cheaply in other ways. Similar scrutiny should be applied to phrases such as “damaging harmonics”. Suppliers should be challenged to quantify what is being damaged, and what, if anything measurable, this is costing each Trust.

The graphic used for lighting invites the conclusion that compact fluorescent lamps would benefit from the deployment of VO, but the consensus seems to be that this is not the case.

3.10.2. Independent Sources of Information

One source of information which appears to be fairly well considered and credible, is a document that has been released by the MOD detailing the anticipated savings for a large number of classes of device and appliance. This appears to be unbiased and fair to the best of my understanding. The Carbon Trust also has material which is accurate and independent.

These documents may be downloaded from the following sites.

http://www.mod.uk/NR/rdonlyres/B9DDB0C5-9611-484B-97AF-1712B8DEC968/0/pg01_10.pdf

http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=CTG045

3.11. Limits of the Decision Making Process

3.11.1. ‘Messy’ Aspects of the decision

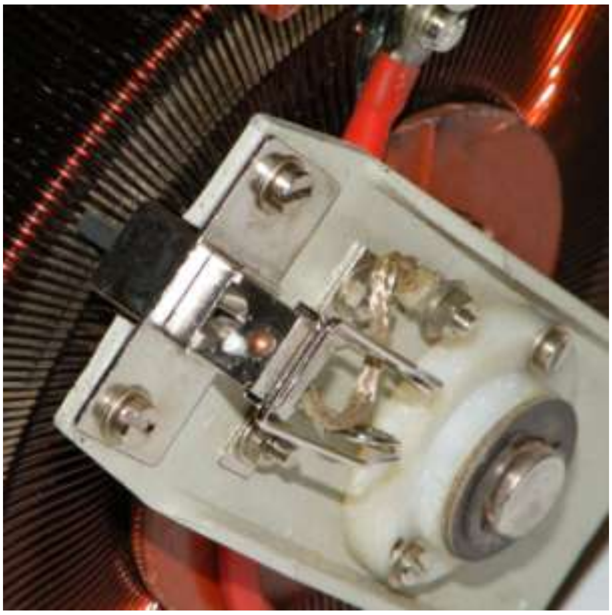
Some aspects of this decision are *messy problems* in the technical *Mason and Mitroff* sense.

The actual life cycle benefits of the project will depend both on the infrastructure and equipment currently in use, the rate of refurbishment of the installed plant and future development of power handling technologies, e.g. the increased use of switched mode power supplies, demand side management, smart metering, etc, and the development of better electrical devices, e.g. LCD displays replacing CRTs, and LEDs and high frequency T5 fluorescents replacing 50Hz magnetic ballast fluorescent lighting. Some of these factors are hard to measure. Others along with future developments are hard to measure.

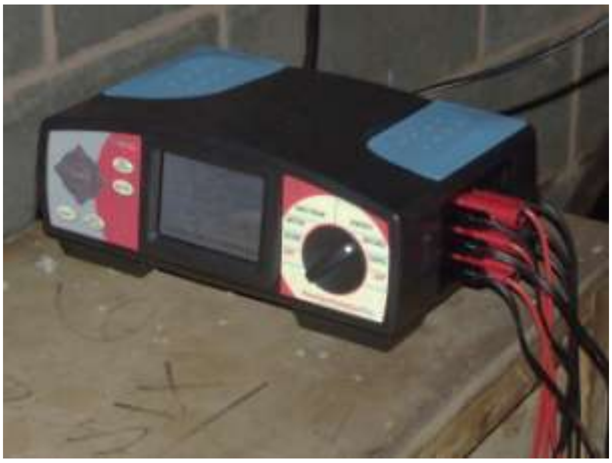
When assessing the likely benefits of VO, an obvious starting point is to survey the equipment installed at a site, but many sites are large and diverse in the equipment that they use, and not all areas can be accessed to be surveyed for reasons of security, hygiene, respect for the dignity of patients, etc.

In theory, all the types of equipment in use might be tested to establish the effect of voltage reduction. This may be done with a variable transformer (sometimes referred to as a *variac*) to vary the applied voltage and a power meter to measure power consumption.

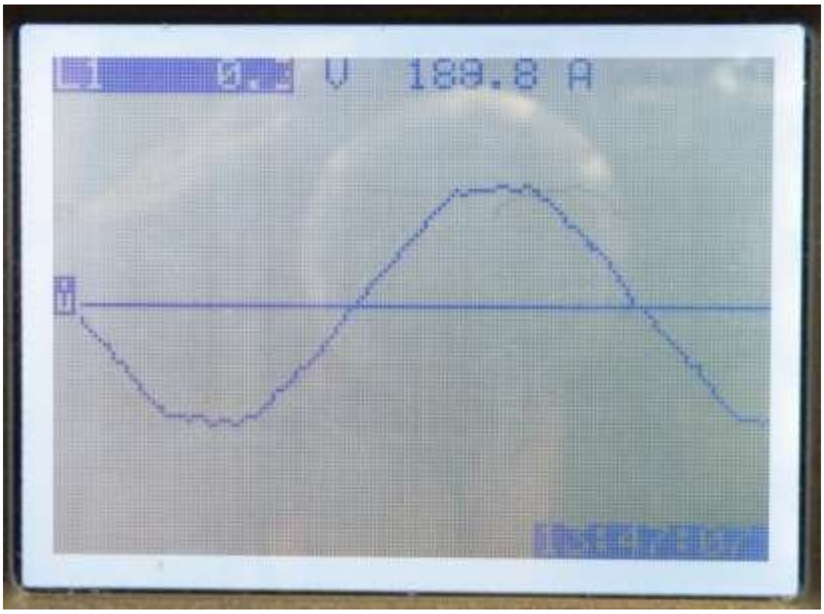
A variac is in effect a toroidal auto transformer, where the output is connected via carbon brush to select the number of turns that contributes to the output voltage. This allows near continuously variable output voltages to be selected for testing.



An electronic power meter such as the unit shown below can measure the power consumed by equipment as voltage is varied.



Such an item of equipment may have many other uses, including logging voltage, current, power, and energy over time allowing current (below) and voltage waveforms to be observed directly. Power factor and harmonics may also be measured directly.



While the direct measurement of power consumption over a range of voltages is potentially useful for widely used fittings or equipment used on a site, it would be too time consuming to test all the types of equipment. Further, even if the voltage to power consumption relationship was known for all items used on the site, the proportion of the time each would be in use could not be known at any instant and could be expected to vary over time.

While we are able to test individual items of equipment then, in general, estimates of the voltage to power consumption relationship must be made for the site in aggregate, which ultimately, while based on some rules of thumb, must be subjective to some extent, and semi quantitative at best .
The estates staff of the Trusts that were interviewed have no inventory of installed plant, equipment or portable appliances and even if such an inventory existed, the duty cycle of operation, i.e. amount of use made of most items of equipment, would be hard to assess.

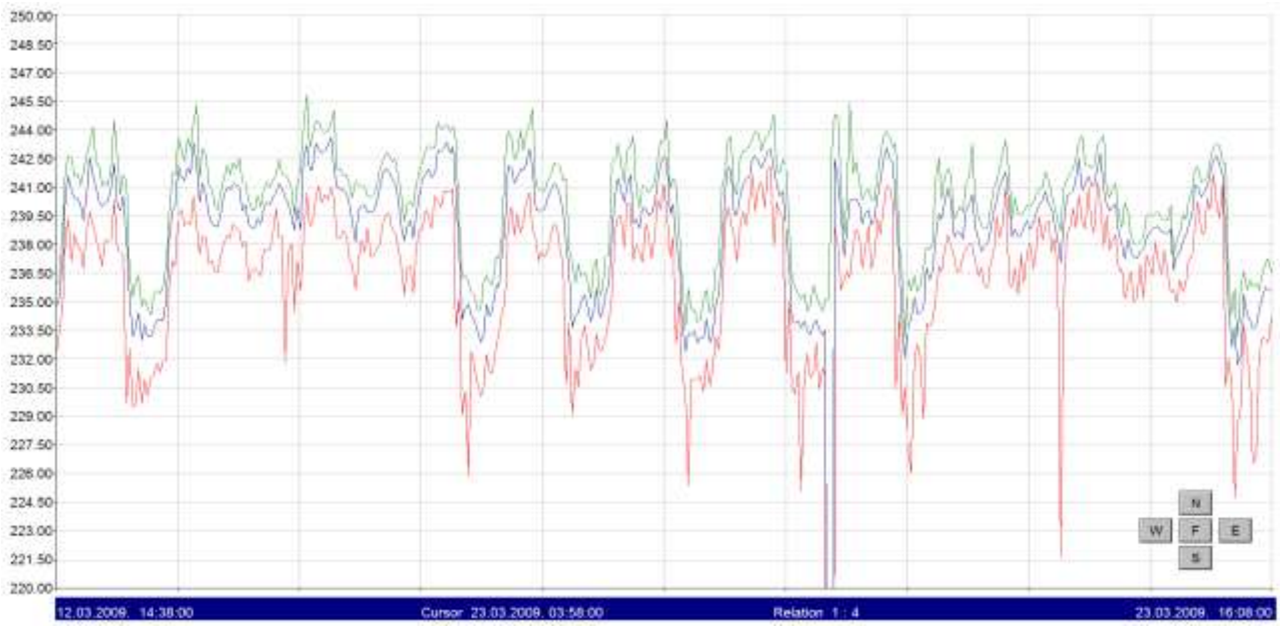
It seems that staff have seldom considered the inventory of electrical loads on hospital sites, but as a useful start the Environmental Manager has cited a rule of thumb from the Technical Services Manager that 65% of electricity used in hospitals is used by lighting. Other than this, within the Trusts, little information was volunteered about the relative amounts of electricity used by the various services and plant.

Even if vendors of VO equipment have a genuine desire to assess the likely outcome of installing this equipment, the making of rigorous predictions about the outcome for the performance of the building or site as a whole is limited by the necessary subjectivity in estimating the way power consumption will vary with voltage. Secondary effects such as the changes to the performance of the space heating system do not generally seem to be considered.

3.11.2. Numeric Data supporting the decision

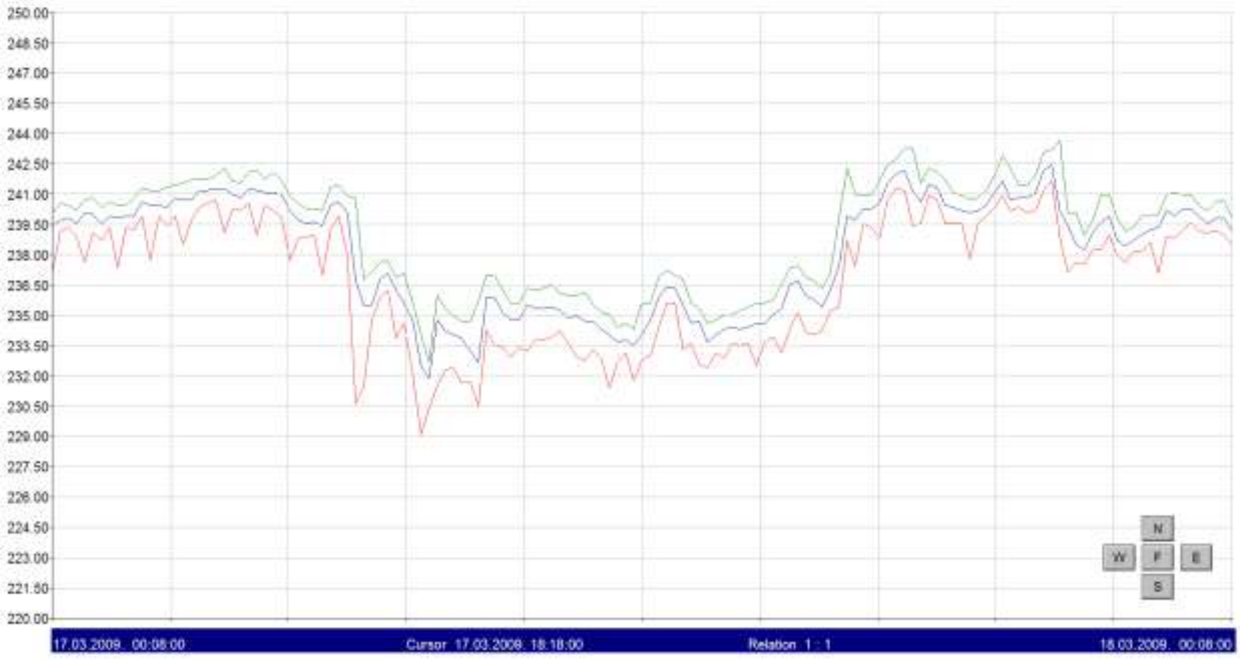
At the heart of decisions about VO is the assumption that voltage is higher than it needs to be, or that it is too high. This must be established by measurement.

It is not enough to measure voltage on a single occasion. We suggest that at a minimum, measurements should be made round the clock for a period of weeks, recording voltage values every few minutes. Each time voltage is recorded, maximum, average and minimum values should be recorded. This should give rise to a graph similar to this one.



Measurements should be made on all phases. Some companies selling VO lend out data loggers which plug into a wall socket, but as voltage may vary significantly within a large building, and it may not always be clear which phase a ring main is connected to, or if these loggers report average or maximum readings, the information produced by such logging should be evaluated with great care.

In some buildings, it may also be appropriate to consider the variation with time of day. The graph below for example shows a maximum of nearly 244 VAC. On this basis, a superficial consideration might accept that VO could be a worthwhile investment. If the building is only in use during normal office hours (e.g. a surgery operating during the day, or an administration building), the voltage is already significantly lower during working hours than a reported maximum 244 VAC might imply.



It seems fairly common that prospective purchasers are either sent data loggers to install themselves, or that the circumstances and significance of logging done by the vendor are not fully explained.

Prospective purchasers should make a point of fully understanding the logging that has been undertaken, and consider how their working hours and electricity demand relate to daily variations in supply voltage.

3.12. Post Decision Performance Reporting

It is a cause of some concern that when expensive equipment has been purchased that proves to be inappropriate or ineffective, decision makers may seek to retrospectively justify their decision to purchase.

When choosing a VO system, prospective users should thus consider which testimonials offer meaningful data and should also examine the completeness and statistical validity of any case studies presented.

I am pleased to report that there has been no evidence of such thinking amongst the collaborators of this project.

Site Observations and Comments

3.13. General Comments

For the pumps encountered during the visits, Grundfos have been able to provide limited technical information.

All UPC models are at least 15 years old, are not electronic and have not been designated efficiency ratings (UPC 80-120, and UPC 40-120).

UPS 50-120F and UPS 32-120F have an energy efficiency rating of C, and the Grundfos help desk have indicated that they are electronic.

D65-120F Single-phase magna - all magna pumps are energy efficiency rating A and are electronically controlled.

Grundfos TPED models are electronic. They are not assigned energy efficiency ratings, but all have high efficiency motors and appear to be electronically controlled.

3.14. Ilkeston Community Hospital

3.14.1. Site Visit


The above left shows the switch room, and to the right, the duct at the end through which VO equipment could be wired in.

Much of the 'behind the scenes' lighting is low energy LED or T5 high frequency fluorescent, some of it on timers. This lighting is unlikely to reduce energy consumption if voltage is reduced.

Within the public areas of the building, a variety of lighting is used, mostly fluorescent.

While some lighting (see above) appears likely to use high frequency electronic ballasts (unlikely to benefit from VO), other lighting (see below) uses 50Hz magnetic ballasts and starters. VO would reduce the energy consumption of this type of lighting but would also reduce its light output. The Trust should consider any implications this might have for health and safety, the 'mood' and psychological effect of the lighting, as much work has clearly gone into designing a well lit and pleasant space.

Estates staff should consult clinical staff re the desirability of reducing light levels in areas used by patients, particularly in mental health units.

Most of the fluorescent lighting has no visible starter inviting the conclusion that electronic ballasts are used. One exception is shown below where access to the starter is restricted by mounting the light against a wooden panel, making maintenance difficult.


One particularly common type of lighting on the site (see below) looks relatively old, but when opened has no starter and appears to use an electronic ballast. It would be expected then, that this load would not be affected by VO.




In addition to lighting, there are a number of loads associated with central heating fluid circulation, air handling, cooling, air conditioning and pumping water.




On this site, estates staff estimate that of the current lighting, about half uses T5 fluorescent and half uses T12 and T8 fittings, though some of the old lighting also appears to have early Transtar electronic ballasts. It might be assumed then, that under half of this lighting might reduce its energy consumption if VO were to be deployed.

Air conditioning is likely to be under thermostatic control, so subject to changes in compressor and fan efficiency. The amount of energy used to run the air conditioning is likely to be broadly unaffected by the implementation of VO.

The circulating pumps and fans that were observed were not electronically controlled and some electricity might be saved by the use of VO, but any systemic impact that reducing the pump output might have on space heating energy consumption has not been established. This is a significant uncertainty.

The water distribution pumps that were examined appear to operate by pumping water into a main until an upper pressure limit is reached, replenishing the water in the main when the pressure drops. The energy required will ultimately depend on the volume of water delivered and the pressures at the pump inlet and outlet, but setting aside any motor and pump efficiency changes due to reduced operating voltage and rotational speed, the amount of energy required is likely to be independent of supply voltage.

3.14.2. The Business Case

For the Ilkeston Community Hospital site, taking the figure of 65% of the energy used for lighting, and 60% of the lighting using electronic ballasts (not reducing its energy consumption in response to VO), an initial assessment of the business case might be made using the 'Simple VO Assessment Tool' (SVAT) supplied with this report.

This suggests a site wide electricity consumption reduction of around 5% might be made, offering a payback time on the investment of a little over 5 years.

By contrast, the proposal from the manufacturer (EMS / Powerstar) indicates a "Guaranteed percentage saving of kWh" figure of 4.5% which agrees well with the estimate we have made. EMS also identifies a payback period of a little over 5 years.

It is interesting however, that EMS have reached these figures by estimating an energy saving of 117 MWh per year, and using an energy price of 4.61p per kWh, where as our simple estimate is based on saving 68MWh with an assumed electricity price of 10p per kWh.

Although our financial predictions happen to agree well, it is clear that our assumptions and methodologies are very different. Had we assumed the same energy price as EMS in our calculations, our simple model would have estimated the payback time as more nearly 10 years, and if the Trust is sourcing electricity at 4.61p, this may be a much more realistic estimate of the payback time.

In line with the different energy savings, our Simple model (nearly 39 tonnes CO_2e per year) and the figures from EMS (a little over 64 tonnes CO_2e per year) predict different carbon savings. EMS appear to have used a reasonable emissions factor for converting saved electricity to saved carbon emissions.

As saving carbon emissions is one of the primary goals of installing VO equipment. It is a matter of some concern that the estimated energy and carbon savings diverge significantly from our own estimates.

Trusts should ask to examine the details by which predicted savings are calculated to verify that the figures presented are plausible and consistent with their own records and calculations.
Trusts should also take care interpreting the findings of the calculations in the light of the other issues raised in this document. Note that many factors are not quantified in our simple model and many are not easy to model in a simple spread sheet.

Voltage Optimisation Assessment Tool (Ilkeston Coomunity Hosp)

Caution ! This tool takes no acccount of the following:
- the cost of borrowing,
- inflation,
- the increased use of switched mode power supplies and technologies
- energy cost changes, or
- changes to the CO_2e emissions factor for electricity.

Enter figures for your site into the blue cells

Proportion of electricity used for lighting	65.00%	
Proportion of electricity used for thermostatically controlled loads	12.00%	
Proportion of electricity used via other switched mode power supplies	15.00%	
The rest	8.00%	
Proportion of lighting with electronic ballasts or power supplies	60.00%	
VO suceptible lighting contribution	26.00%	
Other VO susceptible loads	8.00%	
Total VO susceptible loads	34.00%	
Voltage reduction	8.20%	
Residual voltage	91.80%	
Approximate power reduction for susceptible loads	15.73%	
Approximate residual power consumption for susceptible loads	84.27%	
Approximate site wide power reduction	5.35%	
Approximate residual site wide power consumption reduction	94.65%	
Initial kWh consumption per year	1277791	kWh
Estimated new kWh consumption per year	1209463	kWh
kWh saved	68328	kWh
Energy cost per kWh	£0.1000	
Money saved per year	£6,832.84	
CO_2e Emissions factor	0.57	kg/kWh
CO_2e saved per year	38947.18	kg
Cost of VO installation	£36,339.00	
Payback duration	5.32	years

3.15. Wells Road Centre, Mental Health Unit

3.15.1. Site Visit

Much of the internal lighting uses new fluorescent fittings which are likely to be efficient, but a small amount of halogen lighting is still in use. Where the function of the halogen lighting has an aesthetic role, it may be appropriate to replace it with LED lighting as a 'drop in replacement'.






Assuming the fluorescents are high frequency fittings, they are unlikely to be affected by VO. If the halogen lighting has an inductive transformer its energy consumption might be reduced and its life extended, but its lumens per watt efficiency is likely to be greatly reduced. If the transformers are electronic, they will probably not be affected by VO. If their function is purely cosmetic, the Trust might consider replacing these halogen lamps with LED replacement.

Much of the indoor 'behind the scenes' fluorescent lighting has starters and 50Hz magnetic ballasts. The same is also assumed to be true of the lights in the lift.

Lighting in public areas and areas used by patients, generally appears to use more modern fluorescent designs, some of them T5, using high frequency electronic ballasts.

The fluorescent light type shown below is used widely in this building. It appears likely, on first inspection, that these have electronic ballasts as no starter is visible on the outside of the casing.

When inspected internally however, there is a starter and these lights ought to respond to VO changing the supply voltage.




Some parts of the building are well lit by daylight. Although unrelated to VO, lights in these areas might be switched off automatically as daylight permits.

Exterior lighting generally appears to be efficient. The LED lighting is particularly leading edge, and would not be affected by VO.

The high intensity discharge lighting appears likely to use electronic rather than inductive ballasts and is unlikely to be affected by the installation of VO.

Televisions and office equipment all appeared to be modern. All are likely to have switch mode power supplies and to have an energy consumption unaffected by VO.

A small amount of equipment such as this conveyor belt may use motors which do not use electronic drives, but it is understood that this is only used for a small proportion of the time, so it should have little impact on the outcome of any VO installation.

The kitchen area uses a number of fridges and freezers, but as these are under thermostatic control, the amount of energy they use is likely to be largely independent of supply voltage. The same argument applies to the heated cabinets used to distribute food around the building.

The food mixer is likely to be used until the cooks feel that the ingredients have reached the correct consistency. As a result the energy used is unlikely to be affected by VO, but food preparation might take marginally longer with reduced motor speed.

Similarly, The pharmacy uses a number of fridges, but under thermostatic control, the amount of energy they use is likely to be largely independent of supply voltage.

None of the circulating pumps on this site were obviously under electronic control. These are likely to be affected by VO, but possible wider impacts on the heating system and space heating energy consumption should be considered.

The energy consumption of air condition under thermostatic control should be largely independent of supply voltage.

Some of the air conditioning is marked as "DC INVERTER". This switch mode technology makes the energy consumption further independent of supply voltage.

On this site, a crude estimate suggests that about half of the lighting might use electronic ballasts, but particularly in 'back room' areas, much of the lighting uses magnetic ballasts at 50Hz. It might be assumed then, that around half of this lighting might reduce its energy consumption if VO were to be deployed.

Air conditioning is likely to be under thermostatic control, so subject to changes in compressor and fan efficiency, the amount of energy used to run the air conditioning is likely to be broadly unaffected by the implementation of VO.

The circulating pumps that were observed were not electronically controlled, and some electricity might be saved by the use of VO, but any systemic impact that reducing the pump output might have on space heating energy consumption has not been established. This is a significant uncertainty.

3.15.2. The Business Case

For the Wells Road site, taking the figure of 65% of the energy used for lighting and 50% of the lighting using electronic ballasts (not reducing its energy consumption in response to VO), an initial assessment of the business case might be made using the 'SimpleVoAssessmentTool' supplied with this report.

As the 50Hz magnetically ballasted lighting still appears to be in relatively good condition, it may last longer than the payback period for VO, though the implications of these lights running more dimly should be considered and measurements taken to ensure that all statutory, health and safety, and clinical requirements can be met.

This suggests a site wide electricity consumption reduction of a little over 5% might be made, offering a payback time on the investment of a little over 7 years.

By contrast, the proposal from the manufacturer (power Perfector) indicates a “Guaranteed percentage saving of kWh" figure of 10% which is a significantly higher estimate. Power Perfector also identifies a payback period of a little over 4 years.

It is interesting however, that power Perfector has reached these figures by estimating an energy saving of 168 MWh per year, and using an energy price of 7.9p per kWh, where as our simple estimate is based on saving just under 60 MWh, with an assumed electricity price of 10p per kWh. It is clear that our assumptions and methodologies are very different. Had we assumed the same energy price as EMS in our calculations, the results of our calculations would have diverged even more.

In line with the different energy savings, our Simple model (just over 33 tonnes CO_2e per year), and the figures from Power Perfector (nearly 89 tonnes CO_2e per year), predict different carbon savings. EMS appears to have used a reasonable emissions factor for converting saved electricity to saved carbon emissions.

As saving carbon emissions is one of the primary goals of installing VO equipment, it is a matter of some concern that the estimated energy and carbon savings diverge significantly from our own estimates.

Trusts should ask to examine the details by which predicted savings are calculated to verify that the figures presented are plausible and consistent with their own records and calculations.
Trusts should also take care interpreting the findings of the calculations in the light of the other issues raised in this document. Note that many factors are not quantified in our simple model and many are not easy to model in a simple spreadsheet.

	A	H	I
1	**Voltage Optimisation Assessment Tool (The Wells Road Centre)**		
2			
3	Caution ! This tool takes no acccount of the following:		
4	the cost of borrowing,		
5	inflation,		
6	the increased use of switched mode power supplies and technologies		
7	energy cost changes, or		
8	changes to the CO_2e emissions factor for electricity.		
9			
10	Enter figures for your site into the blue cells		
11			
12	Proportion of electricity used for lighting	65.00%	
13	Proportion of electricity used for thermostatically controlled loads	12.00%	
14	Proportion of electricity used via other switched mode power supplies	15.00%	
15	The rest	8.00%	
16			
17	Proportion of lighting with electronic ballasts or power supplies	50.00%	
18			
19	VO suceptible lighting contribution	32.50%	
20	Other VO susceptible loads	8.00%	
21			
22	Total VO susceptible loads	40.50%	
23			
24	Voltage reduction	7.00%	
25	Residual voltage	93.00%	
26			
27	Approximate power reduction for susceptible loads	13.51%	
28	Approximate residual power consumption for susceptible loads	86.49%	
29			
30	Approximate site wide power reduction	5.47%	
31	Approximate residual site wide power consumption reduction	94.53%	
32			
33	Initial kWh consumption per year	1063009	kWh
34	Estimated new kWh consumption per year	1004846	kWh
35			
36	kWh saved	58163	kWh
37			
38	Energy cost per kWh	£0.1000	
39	**Money saved per year**	£5,816.31	
40			
41	CO_2e Emissions factor	0.57	kg/kWh
42	**CO_2e saved per year**	33152.95	kg
43			
44	Cost of VO installation	£43,090.00	
45	**Payback duration**	7.41	years
46			
47			

Sheet1 Sheet2 Sheet3

Ready

3.16. Leicester, Glenfield Bradgate Mental Health Unit

3.16.1. Site Visit

The lighting throughout the building is relatively modern, and the majority of it appears to use high frequency electronic ballasts. These are unlikely to be affected by VO.

Some lighting is fitted with sensors so it can stay off when people are not nearby.

A small amount of halogen lighting is installed. If the halogen lighting has an inductive transformer its energy consumption might be reduced and its life extended by VO, but its lumens per watt efficiency is likely to be greatly reduced. Electronic transformers for these lights would not be affected by VO.

The external lighting appears to use compact high frequency electronically ballasted fittings. These are unlikely to be affected by VO.

The Grundfos UPC 40-120 pumps are an old model without electronic control. These would be affected by the installation of VO, but even if electricity is saved, this does not guarantee an over-all cost or carbon saving because it isn't clear what the effect on the space heating system might be. Grundfos indicate that these pumps may be over 15 years old, so they may well be replaced before any VO system has covered its costs.

The pumps below appear to be powered directly from the mains. Without electronic control these pumps would be affected by VO, but again, the wider savings and effects are not easy to predict.

The Grundfos UPS 50-120 F and UPS 32-120 F pumps Insert images *are electronically controlled, but only have C energy ratings. It is unlikely that these pumps would be affected by VO.*

The pumps below have an A energy rating and are electronically controlled. They are thus unlikely to be affected by VO.

The fan motors for the air handling system are not electronically controlled so would be affected by VO. It should be established that the lowest speed at which VO could operate the motors would still provide adequate ventilation and heat distribution.


If the effect on the air handling system is not checked, there is a risk that any gains made by reducing electricity costs at the motor would be outweighed by other costs.

If a step up auto transformer were required to maintain the performance of the air conditioning, the cost of this might significantly reduce any financial gains made by site wide voltage reduction. The pumps below have no obvious electronic control and are likely to be affected by VO. Again, checks should be made to ensure that unintended consequences such as reduced central heating circulation do not result in greater energy spend and carbon emissions than would arise without the installation of VO.

At least 15 years old, the UPC 80-120 pumps are not electronic, and have not been designated efficiency ratings. Electricity would probably be saved by VO, but the effect on the system as a whole is not easy to predict. Given their age, these may well have to be replaced with electronically controlled pumps before the VO system has recovered it costs.

The Grundfos TPED pumps have electronic drive and are unlikely to be significantly affected by VO.

On this site, very little of the lighting would be affected by VO.

Some of the circulating pumps and fans that were observed are already electronically controlled. VO might save some electricity in the other pumps, but again, any systemic impact that reducing the pump output might have on space heating energy consumption has not been established which is a significant uncertainty.

3.16.2. The Business Case

For the Glenfield Bradgate Mental Health Unit, taking the figure of 65% of the energy used for lighting and 15% of the lighting reducing its energy consumption in response to VO, an initial assessment of the business case might be made using the 'SimpleVoAssessmentTool' supplied with this report. A sample calculation is shown on the following page.

Because there is such a high proportion of electronically ballasted lighting and some electronically commutated pumps, this suggests that a site wide electricity consumption reduction of a little over 2% might be made offering a payback time on the investment of a nearly 13 years.
The Trust has not yet contacted any manufacturers or installers of VO equipment, so we have no figures with which to compare our results.

Experience suggests however, that different estimators use different 'rules of thumb', assumptions and methodologies and we would suggest that in addition to carrying out their own analysis of the savings, Trusts should get at least three quotes from prospective suppliers.
Trusts should ask to examine the details by which predicted savings are calculated to verify that the figures presented are plausible and consistent with their own records and calculations.
Trusts should also take care to interpret the findings of the calculations in the light of the other issues raised in this document. Note that many factors are not quantified in our simple model and many are not easy to model in a simple spreadsheet.

	A–G	H	I
1	**Voltage Optimisation Assessment Tool (Glenfield Bradgate MHU)**		
2			
3	Caution ! This tool takes no acccount of the following:		
4	the cost of borrowing,		
5	inflation,		
6	the increased use of switched mode power supplies and technologies		
7	energy cost changes, or		
8	changes to the CO_2e emissions factor for electricity.		
9			
10	**Enter figures for your site into the blue cells**		
11			
12	Proportion of electricity used for lighting	65.00%	
13	Proportion of electricity used for thermostatically controlled loads	12.00%	
14	Proportion of electricity used via other switched mode power supplies	17.00%	
15	The rest	6.00%	
16			
17	Proportion of lighting with electronic ballasts or power supplies	85.00%	
18			
19	VO suceptible lighting contribution	9.75%	
20	Other VO susceptible loads	6.00%	
21			
22	Total VO susceptible loads	15.75%	
23			
24	Voltage reduction	7.00%	
25	Residual voltage	93.00%	
26			
27	Approximate power reduction for susceptible loads	13.51%	
28	Approximate residual power consumption for susceptible loads	86.49%	
29			
30	Approximate site wide power reduction	2.13%	
31	Approximate residual site wide power consumption reduction	97.87%	
32			
33	Initial kWh consumption per year	671000	kWh
34	Estimated new kWh consumption per year	656722	kWh
35			
36	kWh saved	14278	kWh
37			
38	Energy cost per kWh	£0.1000	
39	**Money saved per year**	**£1,427.77**	
40			
41	CO_2e Emissions factor	0.57	kg/kWh
42	**CO_2e saved per year**	**8138.29**	**kg**
43			
44	Cost of VO installation	£18,500.00	Est
45	**Payback duration**	**12.96**	**years**
46			
47			

Sheet1 Sheet2 Sheet3

Ready

3.17. General Comments about the Business Case

Although the savings predicted by the 'SimpleVoAssessmentTool' appear to be significant, it should be kept in mind that the older lighting is likely to be replaced in the next few years and possibly before the cost of any VO equipment is recovered.

Presumably, aging pumps will also be replaced as they wear out. Replacement pumps installed now are likely to incorporate low energy electronic controllers, so pumps cannot be relied on to build a business case for voltage optimisation either.

While the initial rate of return appears quite promising, this can be expected to reduce over time as older lighting and plant are refurbished which makes the rate of return on VO hard to predict, but it is likely to be significantly lower than the 'SimpleVoAssessmentTool' predicts.

Any unintended consequences for the heating and ventilation systems are also hard to asses. As these are both hard to model and measure, there is some risk that while electricity may be seen to be saved, in a holistic sense the performance of the sites M&E services will be degraded and some further risk that these changes will never be detected.

Systemic effects of VO which should be risk assessed and valued as part of the business case should include the following;

- Dimming of lighting and any health and safety and psychological implications this may have.
-
- Reduced ventilation and indoor air quality.
  - Increased carbon dioxide levels and any impacts this may have on ability to concentrate and mood.
  - Increased airborne pathogen levels.

- Reduced central heating circulation.
  - Less even heat distribution.
  - Lower return temperatures causing boilers to fire more of the time.

- Reduced electric heating capability.
  - Reduced hot water production.
  - Possible clinical issues arising from time to sterilise / autoclave equipment etc.

Given the above comments about the lighting and pump / fan loads and the lack of information about the systemic effects of varying the pump speed on heat distribution, there seems to be insufficient certainty to build a robust business case for the deployment of VO which will guarantee good cost, energy and carbon savings, despite the simple payback calculation that has been performed.

3.18. Experiment, Data Gathering Analysis

Because hospitals have a varying demand for energy, depending on the number of patients and the season, a simple comparison of energy consumption before and after VO installation is not likely to offer meaningful data.

Even a CUSUM analysis will be difficult to interpret if no period of stable energy consumption can be identified prior to VO installation and many factors which contribute to energy use are changed in a short time frame.

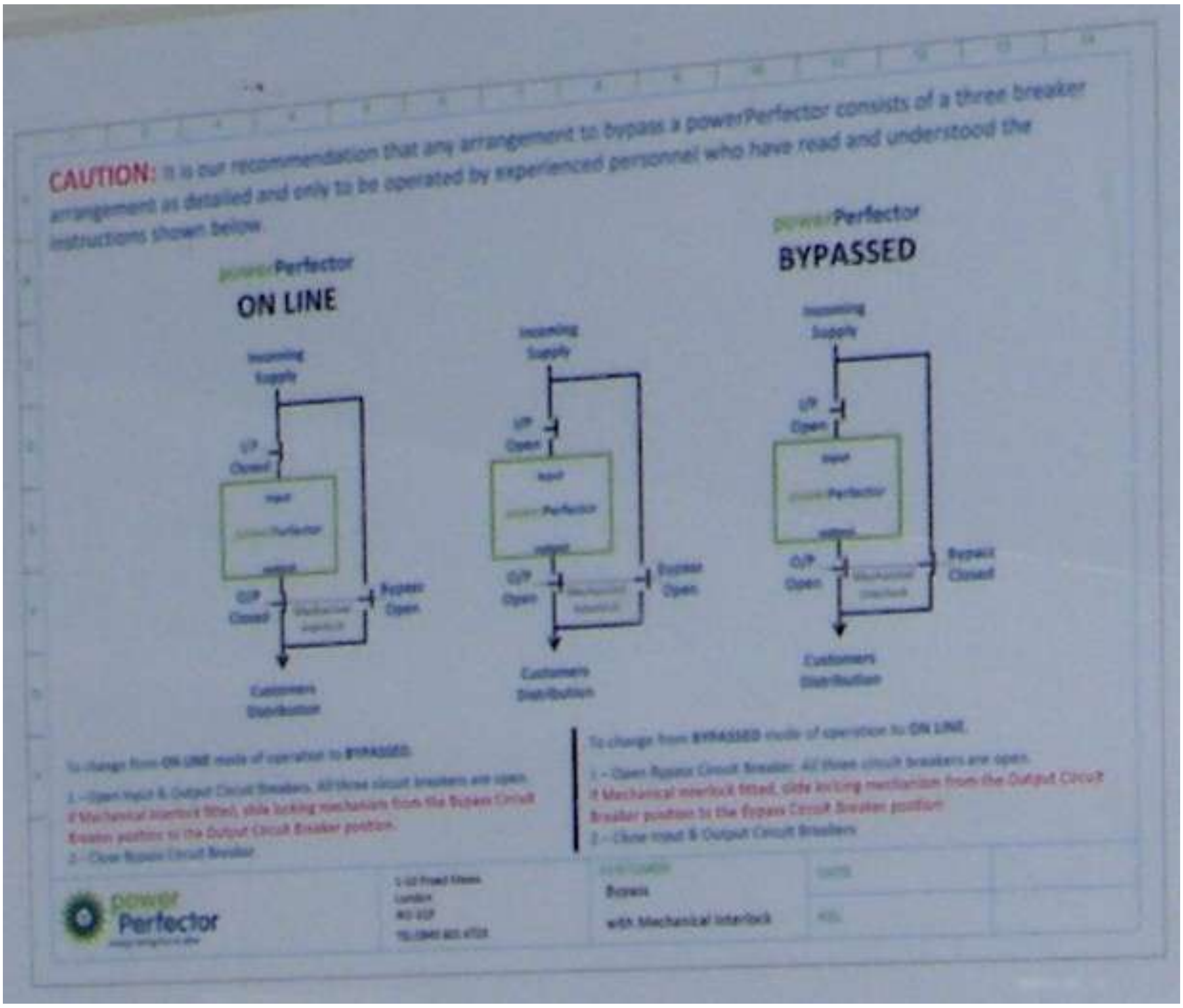
This situation is further exacerbated during periods of refurbishment.

Because the prediction of the benefit arising from VO is not a simple process, we have proposed that the benefit be assessed empirically at a number of sites. We have suggested that once VO has been installed, it be run normally and bypassed on alternate weeks. Logged data, or hourly utility data would then be used to assess the effect of switching the VO in and out using an appropriate statistical method to remove noise from the data collected.

Of the three sites that expressed interest in this project, only one (Wells Road) has installed VO equipment and this in turn has given rise to problems, particularly re the lift system. This has necessitated the fitting of a step-up auto transformer to power the lift from the new 'optimised' site voltage but the presence of this step-up transformer makes switching the VO in and out on an ad hoc basis difficult.

On sites where the loads do not preclude switching the supply through the VO system or putting it on bypass, ease of switching might be a consideration when purchasing. It is for example, our understanding that Power Perfector requires manual switching off of the optimised feed followed by the switching on of the bypass. The potential for error, and the possible cost may result in switching being regarded as onerous and risky, and the brief interruption to supply is obviously undesirable. Further, the switch on surge current as equipment restarts, makes simple 'a second before, a second after' comparisons impossible to make.

By contrast, PoweStar marketing literature states that bypass can be achieved by a single switching operation and that the drop in energy consumption is immediately visible. If true, this ease of demonstrating benefit is of significant value in establishing that VO has a significant benefit. The pictures below show a Power Perfector bypass panel, and the instructions for operating it.


CAUTION: It is our recommendation that any arrangement to bypass a powerPerfector consists of a three breaker arrangement as detailed and only to be operated by experienced personnel who have read and understood the instructions shown below
powerPerfector
ON LINE
powerPerfector
BYPASSED
Incoming Supply
Customers Distribution
powerPerfector

Further problems with switching VO in and out arise from concerns expressed by the IT Operations, that this poses a risk to the Trusts central servers and concerns have also been expressed re the triggering of UPS and backup generator systems.

These factors have prevented the collection of data from a live VO system to date, though it is hoped that it may still be possible to undertake these measurements in the future.

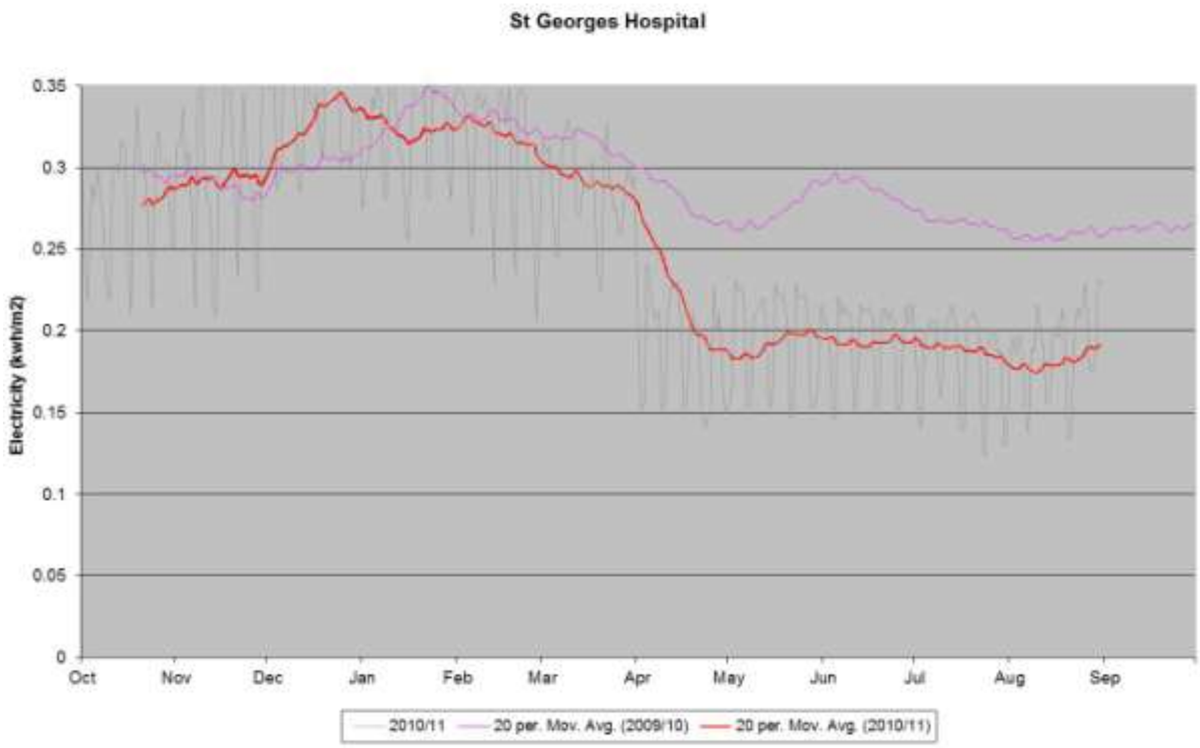
3.19. Electricity Use and Carbon Emissions

Although VO may demonstrably reduce electricity consumption and the carbon emissions that arise from this directly, care should be taken to establish that total carbon emissions are not increased because of changes in the behaviour of the central heating system.

3.20. Feedback from another Trust

NHS Lincolnshire report significant benefit from the use of Power Perfector.

The attached graph shows the effect of voltage optimisation on a good site, though as this has not been inspected as part of this project, it is not possible to comment on how it compares to the three sites which are described earlier in this report.



The Energy and Sustainability manager reports that they have installed 3 units from Power Perfector and found the company to be "competent and professional". The units have so far been free of problems.

By contrast, their relationship with EMS has been less good with only one of two units that were ordered installed. The unit that was installed had a failure of supply that was traced back to a pair of mains fuses not being tightened enough.

Re EMS, the energy and sustainability manager also remarks "I have also heard from other EMS installations that they are not giving the savings they said they would and that in some cases they are not honouring their savings guarantee". It must be stressed that this is only hearsay, and without knowing more about the sites, it is not possible to say if other products might have performed better, or if the lack of performance is due to the loads on site not reducing power and energy consumption in response to reduced supply voltage.

The table below shows the summary of the quote from Power Perfector for additional sites.

Totals	Total Installation Cost	39841
	Total Annual Savings	11145
	Total Annual Energy Savings	111439
	Total Years Payback	3.6
	Installation Cost/Score	1328.0

Beaconfield	Size of Unit	150kVA / 220A
	Load Factor	30
	Installation Cost	14740
	Annual Cost Savings	2833
	Annual Energy Savings	28327
	Month Payback	62
Witham Court	Size of Unit	70kVA / 100A
	Load Factor	43
	Installation Cost	7983
	Annual Cost Savings	2411
	Annual Energy Savings	24107
	Month Payback	40
St Georges	Size of Unit	210kVA / 300A
	Load Factor	38
	Installation Cost	17118
	Annual Cost Savings	5901
	Annual Energy Savings	59005
	Month Payback	35

The Energy and sustainability manager also states that the Trust is considering further installations across other sites. They estimate that a site needs to consume over 80,000kWh per year achieve less than a five year payback. "NHS Lincolnshire has already installed VO at most of our larger sites."

Although these results appear encouraging, we cannot comment on the plant and equipment on those sites and we have no details of the initial mains supply voltage.

We take this as confirmation that on some sites an electricity reduction may be achieved, but cannot comment on any unforeseen and unmeasured effects that may be occurring.

4. Decision Making Processes and Feedback

4.3. Leicester, Bradgate Mental Health Unit

LPT has decided not to install VO for the time being, though there is still some possibility that it might be installed in the next 12 months if the case can be shown to be sufficiently strong. Amongst other sources, the Energy manager. will consider the comments made about VO and this site in this report.

No prospective suppliers have been contacted to date.

To date, the Energy Manager has sought little or no advice on this matter except from the NEP by participation in this project.

The Energy Manager. is concerned that the loads on this site may not justify the cost of VO and is considering these carefully as part of his decision making process and has already begun to learn about the interactions between the various types of load and the supply voltage.

The Energy manager has cited a lack of access to specialist unbiased knowledge to allow Trust staff to differentiate between the various VO offerings and also that some rework of the air conditioning might be required. Options for this might include the following;

- Provision of a step-up auto transformer to keep the existing motors running at their current speed or slightly higher.
- Upgrading the motors to EFF1 standard to increase efficiency, save energy and specify a motor that will run well at the new lower site wide voltage.
- Use an inverter drive to maintain and control motor speed, possibly with a new more efficient motor.

4.4. Ilkeston Community Hospital

It is reported that this Trust had obtained quotes to install VO for the site, and had selected Powerstar as the preferred solution. Having obtained a quote which they felt was justifiable expenditure, bypass panels and other features were added as extras which we understand nearly doubled the price of the system.

This gave rise to the feeling that the Trust could better spend its money on other projects, so for the time being, this project has been put on hold. The Environmental Manager anticipates that the Energy Manager will continue to push for VO to be installed.

The Environmental Manager said that he has spent a significant amount of his own time researching the issue, and reports that his position is one of scepticism.

4.5. Wells Road Centre, Mental Health Unit

From discussions with trust staff it is understood that three VO units have been installed, two in November at Local Services (Duncan Macmillan (DM) site, and one at their Wells Road site).
The Wells Road site is currently being refurbished, so the observations made to date are only based on the initial switchover and the results should not be assumed to be conclusive. The initial observation however, is that they “Can’t see savings”.

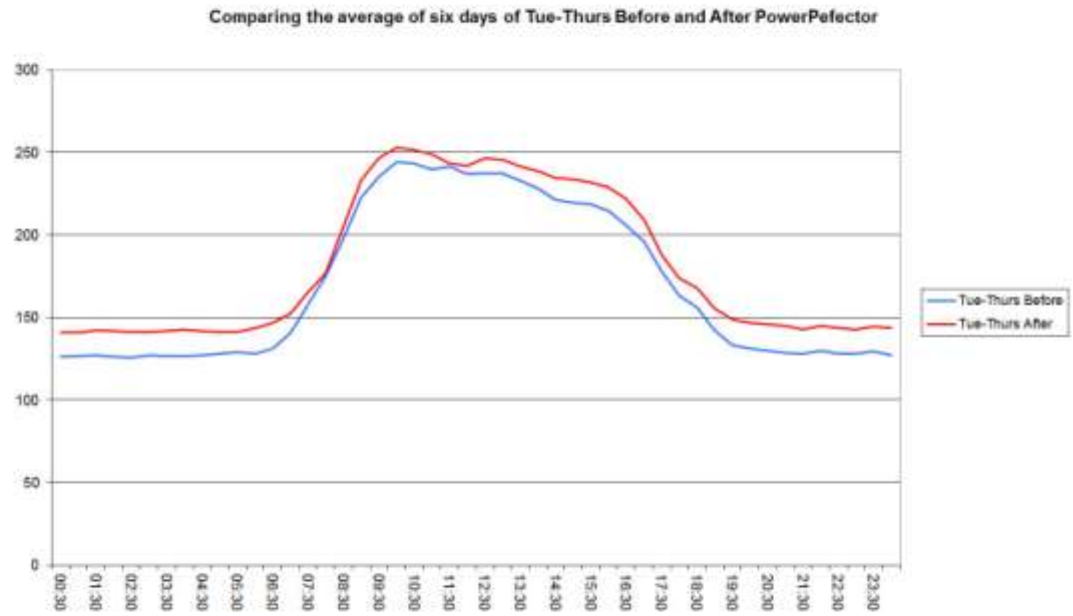
Another VO unit has been installed at Forensics, but this is not operational yet due to problems with the UPS and standby generator.

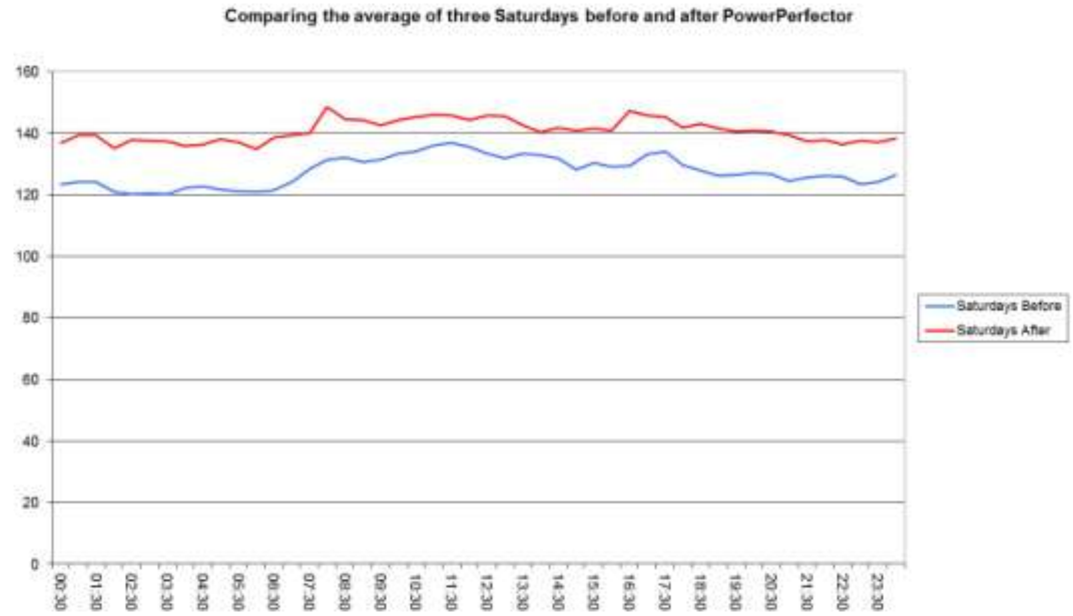
Problems have also been encountered with the lifts on the DM site. These have now been fitted with auto transformers to bring their voltage back up.

Prior to purchase, Trust staff had consulted various online forums and collected relevant information at exhibitions, from journals and from manufacturers.

Surveys by external consultants looked at cost benefit. It was noted that VO equipment had “Carbon Trust accreditation”, that Salix funding was available and that a ‘money back guarantee’ was available. This gave the technology some credibility, though it is worth noting that given the problems that hospitals seem to have in measuring the effect of VO, it may be hard to claim on the guarantee.

Post-installation, they now have “question marks about delivered performance”. Keeping in mind that UK grid voltage is 230VAC + 10 -6%, the system has been set to drop a nominal 232VAC to 218VAC. IT Operations are reluctant to allow the unit to be switched in and out for further testing but the provisional view is that they are now “Looking sceptically at it [VO]”, and “Couldn’t see any discernible change”. Although the data gained so far is of limited value (just the effect of the voltage change in the days immediately before and after commissioning), the following graphs provided by Steve Elkin sum up the grounds for their concern:





The Trust has learned, that once installed, testing and proof of efficacy pose serious difficulties, especially if the reduced voltage has to be stepped up for some items of equipment, and moves to undertake testing are blocked because of the paramount need to keep power on at all times.

5. Alternative Means of Voltage Optimisation

It is generally assumed that VO is a technology for large sites. Increasingly though, there are products available for smaller sites and some companies are now aiming low cost units at the domestic market, see for example http://apexvo.co.uk/ , which might be worth evaluating for use in GPs surgeries and smaller buildings.

It is also generally assumed that VO systems reduce voltage by a fixed ratio and may be bypassed if the external supply voltage fall too low. More sophisticated approaches are available however, and a number of voltage stabilisation products are available. See for example http://www.claudelyons.co.uk/voltage.htm.

There are a number of respects in which the existing technology might be improved, so it is perhaps best to keep an open mind about what the best types of product are.

Another approach might avoid the installation of any additional hardware. Where it has been determined that a site wide reduction in voltage would be appropriate as an alternative to installing a voltage optimisation system as a discrete item of equipment, sites with their own dedicated substation might contact their District Network Operator (DNO). The DNO might agree to change the substation or site transformer tappings to achieve the required voltage reduction.

11 kV site transformer. Check to see if tappings might be changed to achieve voltage optimisation without the installation of additional equipment.

While this would not offer the full range of behaviours claimed for stand-alone VO equipment (e.g. improvement of power factor and harmonics, balancing the three phase supply, protection from high voltage transients, etc), it would achieve the primary goal of voltage optimisation for a moderate labour cost as opposed to a significant hardware cost plus installation charge. This has the additional benefit that no additional space or cabling is required.

Prospective end users of stand-alone VO equipment might challenge suppliers to quantify all the claimed benefits of their products to establish their financial and environmental value and should not be afraid to consider better types of product than those which are heavily marketed, or simpler solutions such a re-tapping at the substation.

6. Discussion

6.3. Pros And Cons

Voltage Optimisation (VO), is generally sold on the basis that a small change in the applied voltage will result in a proportionately larger change in the power and therefore the amount of energy used over time. This is true for simple resistive loads but many ‘real world’ electrical loads are not linear resistors. Because different sites have different ages and mixes of electrical loads, the savings that might be achieved vary significantly from site to site.

The proponents of Voltage Optimisation have endorsed it on a number of grounds which include reduced energy consumption, cost, and carbon emissions, improved power factor, attenuation of high voltage transients, spikes, and surges; and increased equipment life and reduced wear and tear.
Superficially, cost is the main barrier to the uptake of VO solutions, but there are other issues which should be considered.

VO will be a benefit where and if the energy consumption of an appliance can be reduced without reducing the useful output, the rate of work done by the device or where the life of the equipment is usefully extended which reduces the need for expensive maintenance (perhaps in hard to access locations) and the associated ‘down time’. VO can be of particular benefit on sites where motors and other electromagnetic machines are driven at too high a voltage causing magnetic saturation.

Reducing supply voltage can cause difficulties however, and formally proving that reduced voltage will be completely without unintended consequence is impossible. It seems reasonable to expect that the larger and more complex the site on which VO is installed, the greater the probability of some items of plant or equipment being incompatible with the adjusted site voltage and, of the three Trusts visited, two have identified technical problems where a reduced site voltage gives rise to problems and costs over and above those arising as a directly from the installation of the VO equipment itself.

It must also be noted that where VO reduces the useful output of a device or appliance, appliances may need to be operated for longer to do the same amount of work. Where appliances are in constant use, more appliances may be required to provide the same output, or to do the same amount of work.

Another factor which reduces the effect of VO is the continued rise of switched mode technology. Many modern electrical fittings and appliances now use switch mode power supplies of one sort or another and the proportion is increasing all the time. 'Optimising' the supply voltage with these loads does not decrease energy consumption and may cause some additional risk which should be assessed due to increased supply current. This applies to most modern lighting (most LED, modern fluorescent, compact fluorescent lights and halogen lights with solid state transformers), the vast majority of IT, communications and surveillance equipment and motors with electronic and variable speed drives. The increased use of switch mode power supplies is likely to erode the benefits of VO equipment within the period of time that a return on the investment might reasonably be expected. Account should be taken of this when modelling the financial outcomes.

6.4. Digging Deeper

The full effects of voltage optimisation are not always obvious at first sight. For example, even if a motors electricity consumption can be shown to be reduced by VO, it should be questioned if the amount of fluid pumped, or the amount of air blown per kWh is degraded or enhanced. If it is degraded, this raises the possibilities that the performance of the site as a whole might be degraded per kWh of electricity purchased, or that insufficient water would be pumped, or air blown, to meet the users requirement or to comply with regulations.

6.5. Informing The Decision

Trusts have found few good quality independent sources of information on voltage optimisation. This is partly because the topic is complex and the information available is frequently simplistic and biased editorial or advert. Scrutiny should be applied to advertising and promotional materials. Where phrases such as "damaging harmonics" are used, suppliers should be challenged to quantify what is being damaged and what if anything, measurable, is costing each site and Trust. One source of information which appears to be fairly well considered and credible, is a document that has been released by the MOD detailing the anticipated savings for a large number of classes of device and appliance. This appears to be unbiased and fair to the best of my understanding. The Carbon Trust also has material which is accurate and independent.

Some VO marketing techniques that we have heard of appear somewhat disingenuous. It seems fairly common that prospective purchasers are either sent data loggers to install themselves or that the circumstances and significance of logging done by the vendor are not fully explained. Prospective purchasers should make a point of fully understanding the logging that has been undertaken and consider how their working hours and electricity demand relate to daily variations in supply voltage.

It is a cause of some concern that when expensive equipment has been purchased which proves to be inappropriate or ineffective, decision makers may seek to retrospectively justify their decision to purchase. When choosing a VO system, prospective users should thus consider which testimonials offer meaningful data and should also examine the completeness and statistical validity of any case studies presented.

6.6. Assessing The Estate

When assessing the likely benefits of VO, an obvious starting point is to survey the equipment installed at a site, but many sites are large and diverse in the equipment that they use, and not all areas can be accessed to be surveyed for reasons of security, hygiene, respect for the dignity of patients, etc. While the direct measurement of power consumption over a range of voltages is potentially useful for widely used fittings or equipment used on a site, it would be too time consuming to test all the types of equipment. Further, even if the voltage to power consumption relationship was known for all items used on the site, the proportion of the time each would be in use could not be known at any instant and could be expected to vary over time. While we are able to test individual items of equipment, in general estimates of the voltage to power consumption relationship must be made for the site in aggregate, which ultimately, while based on some rules of thumb, must be subjective to some extent, and semi quantitative at best.

The estates staff of the Trusts that were interviewed have no inventory of installed plant, equipment or portable appliances and even if such an inventory existed, the duty cycle of operation, i.e. amount of use made of most items of equipment would be hard to assess.

It seems that staff have seldom considered the inventory of electrical loads on hospital sites. Even if vendors of VO equipment have a genuine desire to assess the likely outcome of installing this equipment, the making of rigorous predictions about the outcome for the performance of the building or site as a whole is limited by the necessary subjectivity in estimating the way power consumption will vary with voltage and secondary unforeseen effects such as the changes to the performance of the space heating system do not generally seem to be considered.

6.7. Problems With Numeric Assessments

A ‘Simple VO Assessment Tool’ spreadsheet has been provided with this report, which Trusts may use to sanity check suppliers proposals,or to develop their own VO assessment models. Both this tool and suppliers proposals frequently indicate that VO could deliver significant savings but the flowing section should be kept in mind.

6.8. Long Term Trends

The actual life cycle benefits of a VO project will depend both on the infrastructure and equipment currently in use on the site, the rate of refurbishment and replacement of the installed plant and equipment, and the future development of power handling technologies, e.g. the increased use of switched mode power supplies, demand side management, smart metering, etc. The development of lower energy electrical devices, e.g. more efficient IT equipment, LCD displays replacing CRTs, and LEDs and high frequency T5 fluorescents replacing 50Hz magnetic ballast fluorescent lighting will also reduce the future benefits of VO. Some of these factors are hard to measure. Future developments, are hard to quantify, but the trend is obvious.

Older equipment, including lighting, is likely to be replaced in the next few years and possibly before the cost of any VO equipment is recovered. Presumably aging pumps will also be replaced as they wear out. Replacement pumps that are installed now, are likely to incorporate low energy electronic controllers, so pumps cannot be relied on to build a business case for VO either. While the initial rate of return appears quite promising, this can be expected to reduce over time as older lighting and plant are refurbished which makes the rate of return on VO hard to predict, but it is likely to be significantly lower than the 'SimpleVoAssessmentTool' predicts.

In addition, the Department of Energy and Climate Change (DECC), predicts a reduction in the carbon intensity of electricity production as the country moves towards meeting its carbon emissions reduction targets. While we do not in any sense wish to use this argument to oppose any energy reduction measure, possible changes in carbon emissions factor might be taken into account when assessing future environmental benefits.

6.9. Unintended Consequences

Any unintended consequences for the heating and ventilation systems are also hard to asses. As these are both hard to model and measure, there is some risk that while electricity may be seen to be saved, in a holistic sense the performance of the sites M&E services will be degraded, and some further risk that these changes will never be detected. Systemic effects of VO which should be risk assessed and quantified as part of the business case should include the dimming of lighting and any health and safety and psychological implications this may have: reduced ventilation and indoor air quality, increased CO_2 levels which may affect ability to concentrate and mood, cause drowsiness and increase airborne pathogen levels.

Reduced central heating circulation might cause a less even heat distribution and lower heating system return temperatures might cause boilers to fire more of the time. Reduced electric heating capability would reduce the rate of hot water production, possibly delaying procedures by increasing the time required to sterilise or autoclave equipment ,etc. In an emergency, or at times of high demand, electrically heated tap water might fail to reach the temperature required to kill legionella reliably.

Given the above comments about the lighting, and the lack of information about the systemic effects of varying fan and pump speeds, there seems to be insufficient certainty to build a robust business case for the deployment of VO which will guarantee good cost along with energy and carbon savings, despite the simple payback calculations that might initially be performed. Further to these technical difficulties, Estates staff should consult clinical staff re the desirability of reducing light levels in areas used by patients, particularly in mental health units as these may pose risks to health and wellbeing, or affect the operational capabilities of the hospital. The risks they pose should be assessed on a site by site basis. A multi-disciplinary approach should be taken to the making of these decisions to attempt to quantify and avoid unintended consequences.

6.10. Problems With Experimental Determination Of Efficacy

Because hospitals have a varying demand for energy, depending on the number of patients and the season, a simple comparison of energy consumption before and after VO installation, is not likely to offer meaningful data. Even a CUSUM analysis will be difficult to interpret if no period of stable energy consumption can be identified prior to VO installation and many factors which contribute to energy use are changed in a short time frame.

Because the prediction of the benefit arising from VO is not a simple process either, we have proposed that the benefit be assessed empirically at a number of sites. We have suggested that once VO has been installed, it be run normally and bypassed on alternate weeks. Logged data, or half hourly utility data would then be used to assess the effect of switching the VO in and out, using an appropriate statistical method to remove noise from the data collected. Of the Trusts involved in this project, only one has actually installed VO (Nottinghamshire Healthcare NHS Duncan Macmillan House). So far, technical and bureaucratic process have precluded the above experimental approach to assessing the efficacy of VO.

The larger a hospital site, the more likely it is that long term changes such as refurbishments will be in progress somewhere on this site. Such work confounds attempts to measure the efficacy of VO.

Further, the more complex a hospital site, the greater the chance that some equipment will require auto transformers, which once installed, make it difficult to bypass the VO as this might cause damage to the equipment normally powered at the 'optimised' voltage. This has been one of the problems encountered at Duncan Macmillan House.

All of these factors make the evaluation and assessment of VO by alternating between optimised and bypassed operation very challenging. Trusts have learned, that once installed, testing and proof of efficacy pose serious difficulties, especially if the reduced voltage has to be stepped up for some items of equipment and moves to undertake testing are blocked because of the paramount need to keep power on at all times in clinical, laboratory, and IT facilities. Brief interruptions to supply when switching on to and off bypass are also an issue.

Additional difficulty in sharing the results of VO trials arises from the differences between sites, and the hazards of simple interpolation from one set of circumstances to another.

6.11. Summary and Conclusion

The optimisation of the performance of the hospital as a whole cannot be achieved just by minimising electricity consumption. A hospital is a complex system, and care must be taken to ensure that minimising electricity consumption does not degrade any aspect of the performance of the whole to an unacceptable degree and as they emerge, new risks (technical, physiological and psychological) should be assessed with clinical staff.

Evidence of efficacy from the project partner Trusts and others is somewhat mixed and anecdotal, with strong endorsements from NHS Lincolnshire, but no discernible improvement noticed so far by Nottinghamshire Healthcare. It would be useful to examine the sites in Lincolnshire that report a strong benefit, and those such as the Wells Road unit in Nottingham, which do not. If possible, the necessary consents should be obtained to undertake a trial, with VO operating, then bypassed on alternate weeks. Only by obtaining enough good data for analysis by experiment, is it likely to be possible to draw statistically meaningful conclusions about which sites benefit from VO. Once this data has been analysed, there would be additional value in further evaluating the sites to establish why some gain more benefit from VO than others.

Prospective end users of stand-alone VO equipment might challenge suppliers to quantify all the claimed benefits of their products to establish their financial and environmental value and should not be afraid to consider better types of product than those which are heavily marketed, or simpler solutions such a changing the selected tap at the substation. Small domestic scale VO units might also be evaluated in smaller buildings to see if useful savings can be made.

Appendix 1 - Project Contacts

Contact details of some of the key people associated with the project:

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