Energy savings from voltage optimisers

Introduction

The Standard Assessment Procedure for Energy Rating of Dwellings (SAP), including Reduced Data SAP (RdSAP), is the UK's National Calculation Methodology (NCM) for dwellings. It satisfies the UK's obligations under the European Performance of Buildings Directive (EPBD) and is used as a compliance tool for new build dwellings, comparing dwelling CO2 emissions to a notional target emission rate.

SAP's purpose as a building regulation compliance tool does not include compliance standards for the delivery of satisfactory building services, in this case electrical services. However, it is a principle of the SAP calculation method that energy savings resulting from a reduction in service delivery will not be counted as an energy saving.

This report considers the estimated energy savings resulting from a reduction in domestic supply voltage to a nominal 220 Volts. This reduction is typically achieved with products known as 'Voltage Optimisers', referred to as 'VOs' in this report. The purpose of this document is to evaluate the potential energy savings of VOs within the UK environment and their applicability to SAP, given that reductions in service delivery will not be counted as an energy saving.

In the first instance it is important to explain the difference between 'voltage dependent' and 'voltage independent' electrical loads, a mixture of which are found in UK homes.

- *A voltage independent load* is an electrical device whose power demand, within its designed operating range, is independent of supply voltage. For example, modern power supply units, such as those for laptop computers and the majority of home electronics devices, are designed to give a fixed voltage output regardless of the supply voltage, allowing them to be used internationally. A typical unit will operate with a nominal input voltage of between 100-240V and the energy consumed therefore remains unchanged, irrespective of the supply voltage to the power supply unit.

- *A voltage dependent load with feedback control* - In considering Voltage Optimisation 'it is important to understand the relationship between power and energy. Electricity suppliers charge for the energy supplied. This will depend on the level of power needed and the length of time the equipment operates for. For some systems with feedback control, often as simple as a thermostat, the amount of energy delivered remains the same, whatever the supply. As a result the system is effectively voltage independent even if the principal device has voltage dependent characteristics.'[1]

- *A voltage dependent load* is an electrical device whose power consumption varies with the voltage being supplied to it and where this is not offset by a feedback mechanism. It is this type of device for which there is a potential energy saving from voltage optimisation.

[1] *Voltage Management – an introduction to technology and techniques*, Carbon Trust - http://www.carbontrust.com/media/77191/ctg045.pdf, accessed 27/06/12

EA Technology Ltd. (EAT) conducted domestic field trials with the VPhase VX1 Voltage Optimiser in early 2010[2]. This trial demonstrated that light and appliance electrical consumption reduced by about 5% on average. The trial appears to have been conducted to a good standard with a reasonable sample size of 50 dwellings; however, there are two problems in accepting the results at face value:

- A proportion of the energy savings will result from service reduction (e.g. dimmer lights)
- Energy savings for domestic loads will diminish with time as newer devices are introduced where supply voltage has no effect upon energy consumption (e.g. switched mode power supplies or inverter driven refrigerators) so the level of savings in year 1 is unlikely to be representative of the savings in later years.

The purpose of this report is to address these two problems by estimating the proportion of energy savings within the EAT field trial which result from a reduced level of service and the replacement timeframe for domestic appliances and lights. The report then estimates an annual and lifetime energy saving to be used to consider whether Voltage Optimisation (VO) should be recognised within SAP.

[2] *Energy Saving Trial Report for the VPhase VX1 Domestic Voltage Optimisation Device*, EA Technology report number 6508 (Issue 2), June 2011.

Energy savings due to a reduced level of service

The most significant domestic electrical loads affected by a reduced level of service are traditional incandescent lamps and mains voltage halogen lamps, since their light output varies with supply voltage and because they use a significant amount of energy. Therefore, a principal objective of this report is to estimate the proportion of the 5% energy saving determined by the EAT field trials that was due to light dimming.

A simple model of the energy consumption of lights and appliances was created to consider this issue. The total energy consumption figures for lights and appliances were taken from the 2009 figures[3] from the 'Housing Energy Fact File 2012' for an average UK dwelling[4]. The total energy consumption for appliances was split into subcategories using consumption data from a report published by Intertek[5], which was the basis for the Energy Saving Trust's 'Powering the Nation'[6] report and based on field data from 250 homes collected in 2010 and 2011. Lighting energy consumption was split into seven subcategories using ownership data from the same source.

For each category it was necessary to estimate the proportion of devices that would benefit from VO and also the expected energy saving for each applicable device, based on a voltage reduction from the UK average of 242V[7] to 220V (a 9.1% reduction). The estimated values are shown in the tables below and discussed in Appendix A. For each category it was then possible to calculate the VO energy saving as a percentage of the total lights and appliances consumption. The percentages for each subgroup were summed to give the total saving due to VO, after subtracting a fixed amount to account for the VO unit's own power consumption equal to 2% of the initial electricity requirement[8].

Initially, VO energy savings were calculated to <u>include</u> the energy savings due to a reduced level of service. In this way, the calculation could be compared to the field trial results as a method of validating the calculation model. The calculation was then repeated with the energy savings due to a reduced level of service removed. The following two tables show the assumptions and results for these two scenarios.

[3] 2009 was the most recent year for which the key data items needed were available.
[4] http://www.carltd.com/sites/carwebsite/files/Housing%20Energy%20Fact%20File%202012_0.pdf
[5] *Household Electricity Survey A study of Domestic Electrical Product Usage*, Intertek report number 66141, May 2012.
[6] *Powering the nation - household electricity-using habits revealed*, Energy Saving Trust, June 2012.
[7] Under European Voltage Harmonisation requirements, in future the UK's supply voltage is likely to be reduced to around 230V, which would have a significant impact on the viability of Voltage Optimisers.
[8] The EAT field trials demonstrated that the power consumption of the VPhase VX1 was approximately 2% of the total electrical energy supplied.

Consumption of average UK dwelling							% of appliances that will benefit from VO	% saving due to VO on applicable appliances	Saving due to VO
kWh/yr						%			%
Lights and appliances	2954	Appliances	2376	Showers	277	9%	0%	0%	0.0%
				Cold	582	20%	95%	11%	2.0%
				Wet	509	17%	95%	3%	0.5%
				Audiovisual	509	17%	30%	17%	0.9%
				ICT	218	7%	20%	17%	0.3%
				Pumps	100	3%	80%	14%	0.4%
				Other	180	6%	30%	17%	0.3%
		Lights	578	Incandescent	346	12%	100%	17%	2.0%
				Halogen	68	2%	100%	17%	0.4%
				Halogen LV	64	2%	50%	17%	0.2%
				Fluorescent	42	1%	50%	17%	0.1%
				CFL	57	2%	25%	17%	0.1%
				LED	0	0%	0%	0%	0.0%
				Other	2	0%	50%	17%	0.0%
Total					**2954**	**100%**	**-**	**-**	**7.2%**
							Parasitic energy consumption of VO device		2%
							Net energy savings of VO		**5.2%**

Table 1 - Estimated energy savings for Voltage Optimisation in 2010 (including savings due to reduced service level)

Consumption of average UK dwelling							% of appliances that will benefit from VO	% saving due to VO on applicable appliances	Saving due to VO
kWh/yr						%			%
Lights and appliances	2954	Appliances	2376	Showers	277	9%	0%	0%	0.0%
				Cold	582	20%	95%	11%	2.0%
				Wet	509	17%	95%	3%	0.5%
				Audiovisual	509	17%	30%	17%	0.9%
				ICT	218	7%	20%	17%	0.3%
				Pumps	100	3%	80%	10%*	0.3%
				Other	180	6%	30%	17%	0.3%
		Lights	578	Incandescent	346	12%	0%	17%	0.0%
				Halogen	68	2%	0%	17%	0.0%
				Halogen LV	64	2%	0%	17%	0.0%
				Fluorescent	42	1%	0%	17%	0.0%
				CFL	57	2%	0%	17%	0.0%
				LED	0	0%	0%	0%	0.0%
				Other	2	0%	0%	17%	0.0%
Total					**2954**	**100%**	**-**	**-**	**4.2%**
							Parasitic energy consumption of VO device		2%
							Net energy savings of VO		**2.2%**

Table 2 - Estimated energy savings for Voltage Optimisation in 2010 (excluding savings due to reduced service level)

* The percentage saving due to VO for pumps is reduced in table 2 due to a likely level of service reduction – this is discussed further in the section on pumps in Appendix A.

Definitions:

- 'Showers' means fully electric showers which heat the water instantaneously at the point of use.
- 'Cold' includes refrigerators, fridge-freezers, upright freezers and chest freezers.
- 'Wet' includes washing machines, washer dryers, tumble dryers and dishwashers.
- 'Audio-visual' includes TVs, DVD/hard-disk players/recorders and set-top boxes.
- 'ICT' includes computers and peripherals, such as monitors, printers, modems and routers.
- 'Pumps' refers to central heating circulator pumps.
- 'Other' (in the appliances section) covers all appliances not part of one of the other groups.
- 'Incandescent' refers to traditional (GLS) lamps.

- ‘Halogen LV’ means *low voltage* halogens, whereas ‘Halogen’ means *mains voltage* halogens.
- ‘Fluorescent’ means linear fluorescent lamps.
- ‘CFL’ means compact fluorescent lamps.
- ‘Other’ (in the lights section) covers all lights not part of one of the other groups.

The calculation results demonstrate that a VO unit which reduces the supply voltage by 9.1% will reduce the electrical consumption of lights and appliances by around 5% (150 kWh/yr, £18/yr) in an average UK home (including the energy savings due to service reduction). This agrees closely with the findings from the EAT field trial, so should represent a reliable baseline. When the energy savings due to service reduction are removed, the predicted energy saving is reduced to around 2.2% (65kWh/yr, £8/yr). This latter result gives an estimate of the saving for the year 2010 that is consistent with the principles of SAP.

It should be noted that this energy saving only represents the reduction in the required electricity to operate lights and appliances. The side-effect of this reduction is a corresponding reduction in dwelling internal heat gains, so the heating system would need to provide more heating energy to maintain the same internal temperature. This process is known as the ‘Heat Replacement Effect’, which is automatically corrected for within SAP (e.g. when low energy lights are selected). The following example illustrates this:

Electricity saved due to VO = 65 kWh/yr
Extra space heating energy required due to reduced gains = 50 kWh/yr
Net saving in delivered energy = 65 – 50 = 15 kWh/yr

Value of electricity saved by VO = £7.45/yr
Value of extra gas used by heating system = £1.55/yr
Net fuel cost saving = £5.90/yr
(20% lower than the gross fuel cost saving)

CO_2 savings due to electricity reduction = 33.6 kg/yr
CO_2 associated with extra gas used = 9.9 kg/yr
Net CO_2 benefit = 23.7kg/yr
(29% lower than the gross CO_2 saving)

How quickly will VO energy savings reduce over time?

It is anticipated that energy savings resulting from the installation of domestic VOs will diminish in future because fewer voltage-dependant devices which benefit from VO will be used in homes. The drivers of this technological change in domestic lighting and appliances, and assumed device replacement rates, are discussed in Appendix B.

The same model used to estimate the energy savings in 2010, was adjusted to consider the likely future savings for VO for the years 2015, 2020 and 2025. The following adjustments were made:

- The energy consumption for lights was assumed to fall by 25% by 2020, based on DEFRA's 2009 report, 'Saving energy through better products'[9]. Assuming a constant rate of decline, a 12.5% reduction was applied for 2015 and 37.5% for 2025. The mix of lighting types present in each year was adjusted to match this level of reduction, assuming a shift away from incandescent lighting towards CFL and LED lighting in later years (see Appendix B).
- The total energy consumption (per household) for appliances was assumed to increase by a constant percentage of 0.5% per year, which is the average rate of increase between 2005 and 2010, based on data from the 2012 Housing Energy Fact File[4].
- The energy use of individual appliance categories was adjusted slightly in each year so that the total matched the inflated figure.
- The proportion of each appliance type assumed to benefit from VO was reduced according to the expected replacement rates described in Appendix B.

Consumption of average UK dwelling							% of appliances that will benefit from VO	% saving due to VO on applicable appliances	Saving due to VO
kWh/yr						%			%
Lights and appliances	2954	Appliances	2448	Showers	277	9%	0%	0%	0.0%
				Cold	550	19%	77%	11%	1.5%
				Wet	500	17%	74%	3%	0.4%
				Audiovisual	550	19%	15%	17%	0.5%
				ICT	250	8%	10%	17%	0.1%
				Pumps	80	3%	55%	5%	0.1%
				Other	241	8%	15%	17%	0.2%
		Lights	506	Incandescent	234	8%	0%	17%	0.0%
				Halogen	87	3%	0%	17%	0.0%
				Halogen LV	66	2%	0%	17%	0.0%
				Fluorescent	39	1%	0%	17%	0.0%
				CFL	75	3%	0%	17%	0.0%
				LED	3	0%	0%	0%	0.0%
				Other	2	0%	0%	17%	0.0%
Total					**2954**	**100%**	**-**	**-**	**2.8%**
								Parasitic energy consumption of VO device	2%
								Net energy savings of VO	**0.8%**

Table 3 - Estimated energy savings for Voltage Optimisation in 2015 (excluding savings due to reduced service level)

[9] https://www.gov.uk/government/publications/saving-energy-through-better-products-and-appliances

Consumption of average UK dwelling							% of appliances that will benefit from VO	% saving due to VO on applicable appliances	Saving due to VO
kWh/yr						%			%
Lights and appliances	2943	Appliances	2509	Showers	277	9%	0%	0%	0.0%
				Cold	500	17%	59%	11%	1.1%
				Wet	480	16%	53%	3%	0.3%
				Audiovisual	550	19%	8%	17%	0.2%
				ICT	250	8%	5%	17%	0.1%
				Pumps	70	2%	30%	5%	0.0%
				Other	382	13%	8%	17%	0.2%
		Lights	433	Incandescent	146	5%	0%	17%	0.0%
				Halogen	91	3%	0%	17%	0.0%
				Halogen LV	69	2%	0%	17%	0.0%
				Fluorescent	36	1%	0%	17%	0.0%
				CFL	78	3%	0%	17%	0.0%
				LED	11	0%	0%	0%	0.0%
				Other	2	0%	0%	17%	0.0%
Total					2943	100%	-	-	1.8%
							Parasitic energy consumption of VO device		2%
							Net energy savings of VO		-0.2%

Table 4 - Estimated energy savings for Voltage Optimisation in 2020 (excluding savings due to reduced service level)

Consumption of average UK dwelling							% of appliances that will benefit from VO	% saving due to VO on applicable appliances	Saving due to VO
kWh/yr						%			%
Lights and appliances	2933	Appliances	2572	Showers	277	9%	0%	0%	0.0%
				Cold	500	17%	41%	11%	0.7%
				Wet	480	16%	32%	3%	0.2%
				Audiovisual	550	19%	4%	17%	0.1%
				ICT	250	9%	3%	17%	0.0%
				Pumps	60	2%	5%	5%	0.0%
				Other	455	16%	4%	17%	0.1%
		Lights	361	Incandescent	55	2%	0%	17%	0.0%
				Halogen	77	3%	0%	17%	0.0%
				Halogen LV	77	3%	0%	17%	0.0%
				Fluorescent	37	1%	0%	17%	0.0%
				CFL	87	3%	0%	17%	0.0%
				LED	26	1%	0%	0%	0.0%
				Other	2	0%	0%	17%	0.0%
Total					2933	100%	-	-	1.2%
							Parasitic energy consumption of VO device		2%
							Net energy savings of VO		-0.8%

Table 5 - Estimated energy savings for Voltage Optimisation in 2025 (excluding savings due to reduced service level)

The predicted energy savings from VO, net of savings due to a reduced level of service, are summarised in Table 6 below.

Year	Predicted VO energy saving
2010	2.2%
2015	0.8%
2020	-0.2%
2025	-0.8%

Table 6 - Predicted Voltage Optimisation domestic energy savings from 2010 to 2025

The analysis of future energy savings is inevitably based on uncertain assumptions regarding the uptake of current and future technologies, but this study indicates that it is likely VO related energy savings will diminish significantly within their lifetimes. Therefore, it would be incorrect to attribute the year 1 energy saving to VOs for each subsequent year of their lives, or to assume a long lifetime for the purpose of estimating energy, cost, or carbon savings. The possibility of a negative energy saving (due to the unit's own operational consumption) should also be given detailed consideration, since it would not be desirable for the VO to become an energy-consumer later in its lifetime, particularly if there will be an additional cost associated with removal.

If a VO device was installed in an average UK home in 2013, interpolating between the figures for each 5 year estimate above, it would be expected to save electrical energy for around 7 years, with an average annual saving during that period of 0.6% per year (18kWh/yr, £2 per year). If installed in a future year, both the lifetime and the average annual saving should be reduced further, as indicated in Table 7.

Year of installation	Average energy saving per year during lifetime	Energy saving lifetime
2010	1.0%	10
2011	0.9%	9
2012	0.8%	8
2013	0.6%	7
2014	0.5%	6
2015	0.4%	5
2016	0.3%	4
2017	0.2%	3
2018	0.1%	2
2019	0.0%	1

Table 7 - Predicted Voltage Optimisation related domestic annual energy savings and lifetimes

If the replacement of older domestic lighting and appliances does not take place as quickly as assumed, the savings would be higher for longer. As a sensitivity test, the analysis was repeated with half the replacement rates assumed for every category, resulting in the following alternative table (Table 8).

Year of installation	Average saving per year	Energy saving lifetime
2010	1.0%	20
2011	0.9%	19
2012	0.9%	18
2013	0.8%	17
2014	0.8%	16
2015	0.7%	15
2016	0.7%	14
2017	0.6%	13
2018	0.6%	12
2019	0.6%	11

Table 8 - Predicted Voltage Optimisation related domestic annual energy savings and lifetimes (halved replacement rate)

However, it is important to note that the replacement rates for the principal domestic electrical appliances that can benefit from energy savings as a result of VO (cold appliances, wet appliances and audio-visual appliances) have been consistently high for many years. European legislation, including energy labelling and Ecodesign (Energy Related Products Directive), means that efficiency improvements are likely to continue to be made over time, as assumed in the modelling.

Furthermore, after correcting for the Heat Replacement Effect the benefits would be lower than when considering the lights and appliance energy savings in isolation, as above. Typically, fuel cost savings would be approximately 20% lower, whilst CO_2 saving would be reduced by approximately 30%.

Conclusions

- When including the energy savings due to a reduced level of service, installing a VO within an average UK dwelling would, in 2010, have reduced the electrical consumption of lights and appliances by approximately 5% (150kWh/yr, £18/yr) during the first year of operation.
- Removing the energy savings due to a reduced level of service, energy savings for the first year of operation would have been approximately 2.2% (65kWh/yr, £7/yr).
- Average energy savings for VOs now are probably lower than this 2010 estimate and are expected to continue to fall as domestic lighting and appliance technology improves. Therefore, year 1 energy savings are not an accurate reflection of the on-going benefits.
- The rate at which VO energy savings will fall is uncertain, but this study indicates that by around 2020 energy savings may drop to zero and then become negative due to the VO unit's internal power consumption.
- If it were considered appropriate to assess the energy savings resulting from domestic VO installations, this report suggests the energy savings for an installation that occurs in 2013 would be, on average, 0.6% of the dwelling's energy consumption for lights and appliances, lasting for a period of 7 years only. This equates to an average energy saving of 18kWh/yr, or an electricity bill saving of £2/yr. The benefits would be further reduced by the Heat Replacement Effect, which is applied automatically in SAP and other models.
- The energy savings and lifetime should be adjusted downwards for VOs installed in future years (e.g. 0.4% for 5 years if installed in 2015).

Recommendation for SAP

SAP does not account for the energy use of appliances for calculating the SAP rating, Dwelling Emission Rate or the operating costs stated on the Energy Performance Certificate. It is therefore unable to reflect appliance energy savings from VOs. However, for the Green Deal Occupancy Assessment and other possible future uses SAP, appliance consumption is estimated and energy savings derived from VOs could therefore be assessed. This would require the collection of additional data, including a reliable measure of the average on-site voltage to determine installation viability. Adjustments would also be required to the calculation methodology. Any decision related to the recognition of VO in SAP should carefully consider the requirement to increase the complexity and cost of SAP assessments and the required dwelling survey with respect to the scale of energy savings.

Given that the energy saving potential appears to be small (representing a typical cost saving of approximately £2/yr) and short lived, the added complexity of recognising Voltage Optimisation in SAP does not appear justified. It is therefore recommended that Voltage Optimisation is not recognised within SAP calculations.

Appendix A – Lighting and appliance subgroups: proportion that will benefit from Voltage Optimisation

For each subcategory of appliances considered in this report an estimate was required of the proportion of the stock of that lighting/appliance type that will benefit from VO and the likely reduction in energy consumption of an applicable appliance when the voltage is reduced from 242V to 220V. Since the initial aim of the study was to recreate the results of the field trials, the figures provided are deliberately estimates for the year 2010. Appendix B considers how these numbers might change in future.

Electric showers

Assumption: 0% of electric showers could benefit from VO.

Electric showers are a resistive load and as such a decreased supply voltage will result in an increase in power demand. However, it will also reduce the performance of the shower by resulting in a lower flow rate for the same temperature setting, or alternatively a cooler shower at the same flow rate. Therefore electric showers would not benefit from VO.

For other appliance types where there is a reduction in level of service the saving was included in the initial base-line calculation for comparison with the EAT field trials. However, in those trials electric showers were not on VO treated circuits so it would not have been correct to do the same for electric showers. It was still necessary to include this category for completeness in order that the appliance consumption would add up to the correct total.

Cold appliances

Assumption: 95% of cold appliances could benefit from VO. Of those, the average energy saving due to VO would be 10.5%.

It was assumed that all older cold appliances would benefit from VO, but that the most efficient new cold appliances (rated A+ or better) would not. This is consistent with testing carried out by EA Technology showing that whilst there was a significant energy saving for a B-rated appliance, there was no saving for an A+ model[10].

Approximately 37% of cold appliances sold in 2010 were rated A+ or better, representing about 2.5% of the total stock. Assuming another 2.5% of the stock was already A+ or better gives an estimate that 5% of the stock will not benefit from VO and therefore 95% will.

The energy savings for a B-rated appliance (which is close to the average rating for the UK cold appliance stock), was shown in the EAT study to be 12.5% when the voltage was reduced by 10.8%. Correcting this energy saving to the voltage reduction of 9.1% assumed for this study gives an estimated energy saving of 10.5%.

[10] *Appliance Efficacy Study*, EA Technology report number 83880, August 2012.

Wet appliances

Assumption: 95% of wet appliances could benefit from VO. Of those, the average energy saving due to VO would be 3%.

As with cold appliances, it was assumed that only the most efficient new wet appliances would not benefit from VO. This was also assumed to be 5% of the total, leading to the estimate that 95% of devices could benefit from VO.

Only a small proportion of the electrical energy used by wet appliances is voltage dependant, so the potential energy saving was assumed to be much lower than for cold appliances. This is because the air or water heating aspect of wet appliances is an electrical resistive load controlled by thermostats, where VO will not enable an energy saving for these appliance components.

Data from the Market Transformation Programme[11] on the energy use of washing cycles at various temperatures enabled the estimation that the proportion of energy used for heating in a 50°C wash is about 83% of the total, with the remainder assumed to be used for agitation (i.e. in motors). Therefore, 17% of the total is likely to be affected by VO. Of this, the power (and therefore energy) reduction was assumed to be proportional to the square of the voltage drop, i.e. 17.4% for a 9.1% voltage reduction, and the energy saving per device was calculated as: 17.4%*17% = 3.0%.

Audiovisual appliances

Assumption: 30% of audiovisual appliances could benefit from VO. Of those, the average energy saving would be 17.4%.

Modern audiovisual (AV) devices make use of solid state electronics operating at low DC voltages and typically require built in power management to appropriately condition the incoming mains power. In almost all cases new AV appliances use switched-mode power supplies (PSUs), which are designed to draw the same amount of power over a large range of international voltages. Therefore, it was assumed that only old equipment remaining in the stock will benefit from VO, for example older CRT televisions. This was estimated to account for 30% of the AV appliances stock in 2010.

Of those appliances that could benefit from VO, it was assumed that their power consumption is proportional to the square of the voltage; hence the energy savings from a 9.1% voltage reduction would be approximately 17.4%.

ICT appliances

Assumption: 20% of ICT appliances could benefit from VO. Of those, the average energy saving would be 17.4%

Similar to audiovisual (AV) appliances, almost all newer ICT appliances make use of switched-mode power supplied which consume the same amount of power regardless of the supply voltage. Only older ICT peripherals are likely to benefit from VO (e.g. old printers and modems) – estimated to be 20% of the total in 2010.

[11] *BNW01 - Combined Laundry: Government Standards Evidence Base 2009: Key Inputs*, Market Transformation Programme, 2009.

Of those benefitting, the standard reduction of 17.4% was assumed, as described previously.

Pumps

Assumption: 80% of central heating pumps could benefit from VO. Of those, the average energy saving would be 14% (reduced to 10% when the reduction in level of service is removed).

As a result of Ecodesign legislation, all major central heating pump manufacturers are now or will shortly be manufacturing pumps with variable speed drive technology, which means that the electrical load becomes voltage independent. However, there are a large number of older pumps within the housing stock which could potentially benefit from running at a lower voltage. The EA Technology study[10] showed that, for such pumps, when the voltage was reduced by 10.8% the power consumption fell by 17%. Rescaling this energy saving to the voltage reduction assumed in this study (9.1%) gives an estimated energy saving for applicable pumps of 14%.

This is complicated by the fact that virtually all of the energy supplied to the pump ends up as heat in the circulating water (which is presumably useful if the pump is running in the first place). When this heat is reduced by the presence of VO, more will be required from the boiler, so the net benefit will be reduced. However, for the purposes of comparison with the field trial figure (where this heat replacement would not have been measured), this was ignored.

A final complication is that the EA Technology study[10] also found a reduction in pump flow rate (of about 4%) as a result of the voltage reduction. This was roughly corrected for by subtracting a further 4% of the energy saving within the scenarios where the energy savings due to a reduced service were removed (but not for comparison with the field trials).

Other appliances

Assumption: 30% of other appliances could benefit from VO. Of those the average energy saving would be 17.4%.

This category incorporates all kinds of devices and so is difficult to evaluate. However, many electronic devices used in homes now utilise solid state electronics and switched-mode PSUs. However, older electronic appliances, as well as some new ones, like vacuum cleaners, probably could benefit from VO. It is assumed these make up 30% of the energy consumption of the ‘other appliances’ category.

Of those benefitting, the standard reduction of 17.4% was assumed, as described previously.

Lights

Assumptions:

- *100% of incandescent GLS and halogen mains voltage lamps could benefit from VO (reduced to 0% when the energy savings from a reduction in service are removed).*
- *Around 50% of low voltage halogen and linear fluorescent lamps could benefit from VO (reduced to 0% when the energy savings from a reduction in service are removed).*
- *Around 25% of CFLs could benefit from VO (reduced to 0% when the energy savings from a reduction in service are removed).*

- *No LED lamps could benefit from VO.*
- *The energy savings from VO for applicable incandescent GLS and halogen lamps will be 17.4%.*
- *The energy savings from VO for applicable fluorescent (linear and CFL) lamps will be 17.4%.*

Traditional incandescent (GLS) lamps and mains voltage halogens are simple resistive loads so they would consume approximately 17.4% less power, on average, where VO is used. However, they will also be dimmer, so the energy savings are removed in all scenarios other than for direct comparison with the field trial results.

Fluorescent lamps (CFL or linear) can have inductive or electronic ballasts, with the latter being essentially voltage independent and therefore offering no VO energy savings potential. The power consumption of CFLs with inductive ballasts, which are becoming less prevalent, has been shown to vary significantly with voltage – a report by the University of Sheffield[12] showed that power consumption falls sharply in such devices as the voltage is reduced. However, there is also a reduction in the level of light provided, so this energy saving is reduced to zero where level of service reductions are removed. It was estimated that around 50% of linear fluorescent lamps and 25% of CFLs have inductive ballasts and could benefit from VO.

There is no significant legacy stock of LED lighting, which means we can assume they all utilise modern power supply technologies; therefore it was assumed that no LED lights could benefit from VO.

[12] *Mini Project No 1 – Voltage Optimisation: Lighting*, Martin Braun, University of Sheffield, Feb 2012.

Appendix B – Drivers of appliance efficiency improvement and consideration of appliance replacement rates

Cold appliances

European Commission Regulation (EC) No 643/2009 is intended to improve the efficiency of refrigeration appliances. This is expected to result in new models increasingly using variable speed drive controls, decoupling their energy use from the supply voltage.

MTP Programme Bulletin: Domestic Cold Appliances, February 2012, states:

"The market for cold appliances in the UK is changing in response to the latest Ecodesign and Labelling Regulations. This EU legislation has resulted in the least efficient products being removed from the market and encouraging the development of more efficient products.

There does not appear to have been any significant technological developments such as the introduction of vacuum insulated panels (VIPs). Efficiency improvements have been due to more efficient compressors, improved insulation and electronic controls."

The final sentence mentions more efficient compressors (clarifying later that this refers to variable speed drive compressors) and electronic controls, suggesting new appliances are less likely to benefit from VO. This assumption is further supported by the findings of EA Technology's 'Appliance Efficacy' study 10 from August 2012, which found decreasing VO savings as cold appliance efficiency rating improved.

For this reason it was assumed in this analysis that the proportion of devices sold which benefit from VO will decrease over time. Bearing in mind that 37% of the cold appliances sold in 2010 were rated A+ or better, the following proportions were assumed:

- 2010 to 2015: 50% of new cold appliances sold will not benefit from VO
- 2015 to 2020: 75% of new cold appliances sold will not benefit from VO
- 2020 onwards: All new cold appliances sold will not benefit from VO

There is also a large stock of existing appliances which will continue to benefit from VO in future years, so it was necessary to consider the likely replacement rate of these with newer models. According to Market Transformation Programme figures[13], 40.43 million cold appliances were present in UK homes in 2010. The number of new cold appliances sold was 2.88 million, implying that about 7.1% of cold appliances are replaced each year. By combining this with the assumed proportion of new appliances which will benefit from VO, we can estimate the rate at which the proportion of cold appliances benefiting from VO will reduce over time as shown in the following table:

Table B1: Estimated proportion of cold appliance stock benefitting from VO

2010	2015	2020	2025
95%	77%	59%	41%

[13] *BNC001 - Domestic Chest, Freezers, Upright Freezers, Fridges and Fridge-freezers: Government Standards Evidence Base 2009: Key Inputs*, Market Transformation Programme, June 2010.

Wet appliances

Commission Regulations (EC) 1015/2010, 1016/2010, and others, are intended to improve the efficiency of domestic wet appliances. The benefits of VOs on wet appliances are limited to the non-heating aspects of their energy use (e.g. the energy used in motors to agitate the contents) since the heat input is a thermostatically controlled electrical resistive load that is therefore independent of supply voltage. This report assumes that the split between the energy used for heating and the energy used for agitation is 83:17, as described in Appendix A.

Given the regulatory and technology background, it is assumed that an increasing proportion of wet appliances sold in future will have variable speed drive controls and more sophisticated power management. Therefore, the proportion of new appliances benefitting from VO was assumed to reduce over time as follows:

- 2010: 50% of new wet appliances sold will not benefit from VO
- 2015: 75% of new wet appliances sold will not benefit from VO
- 2020 onwards: All new wet appliances sold will not benefit from VO

It was assumed that 5% of the stock of wet appliances in the base year (2010) would not benefit from VO, as described in Appendix A.

According to Market Transformation Programme figures11, 25.19 million washing machines (including washer-dryers) were present in UK homes in 2010. The number of new washing machines sold in that year was 2.13 million, implying that about 8.4% of washing machines are replaced each year. It was assumed that other wet appliances would have the same rates as washing machines. By combining this rate with the estimated proportion of new appliances not benefitting from VO, the proportion of the stock benefitting from VO in future years was estimated to be as follows:

Table B2: Estimated proportion of wet appliance stock benefitting from VO

2010	2015	2020	2025
95%	74%	53%	32%

Audiovisual, ICT and other appliances

Older audiovisual, ICT and other appliances are likely to use simple transformer-based power supplies (so they *are* likely to benefit from VO), whilst newer ones are likely to use switched-mode power supplies designed to operate at any voltage from 100-250V with very little effect on their power consumption. This change has been driven in part by a number of European Commission Regulations relating to specific product types included in these groups. Most new appliances will therefore be unlikely to benefit from VO, but the significant stock of older ones will take some time to disappear. This report assumes that the proportion of appliances in these groups that benefit from VO will halve every 5 years as the stock of old appliances gradually decays, as shown in the following table:

Table B3: Estimated proportion benefitting from VO				
Type	2010	2015	2020	2025
Audiovisual	30%	15%	8%	4%
ICT	20%	10%	5%	3%
Other	30%	15%	8%	4%

Pumps

This category refers to the circulation pumps used in central heating systems, which use a significant amount of energy because they operate for long hours for most of the year and are present in the vast majority of UK homes. Older pumps are likely to benefit from the presence of VO. However, the power consumption of new circulation pumps has been reduced considerably over recent years. The recent release of Commission Regulation (EC) No 641/2009 will consolidate improvements in performance that have been made. It is assumed that all future products will incorporate variable speed drives and so any new pumps sold are unlikely to benefit from VO in future.

For 2010, it is estimated that approximately 80% of pumps in the existing housing stock were of the older type and that 5% of the stock of pumps will be replaced each year, leading to the following estimates of the proportion of dwellings with pumps that will benefit from VO in future years:

Table B4: Estimated proportion of CH pump stock benefitting from VO

2010	2015	2020	2025
80%	55%	30%	5%

Lights

Sales of most types of incandescent lamps are already prohibited in the UK and all new lamps must display their energy rating at the point of sale. The balance of the stock is therefore expected to move away from incandescent lamps fairly quickly towards CFLs and halogens and, in later years, towards LEDs.

Table B5: Assumed change in lighting technology mix

	2010	2015	2020	2025
Incandescent	38.4%	25.0%	15.0%	5.0%
Halogen	16.1%	20.0%	20.0%	15.0%
Halogen LV	15.2%	15.2%	15.2%	15.2%
Fluorescent	6.0%	5.4%	4.8%	4.3%
CFL	23.5%	30.0%	30.0%	30.0%
LED	0.6%	4.2%	14.7%	30.2%
Other	0.3%	0.3%	0.3%	0.3%
TOTAL	100.0%	100.0%	100.0%	100.0%

The mix of lighting types assumed has no bearing on the savings for VOs in this study (other than in the uncorrected 2010 base case), since it is assumed that lights do not benefit from VO without causing a reduction in the level of service.