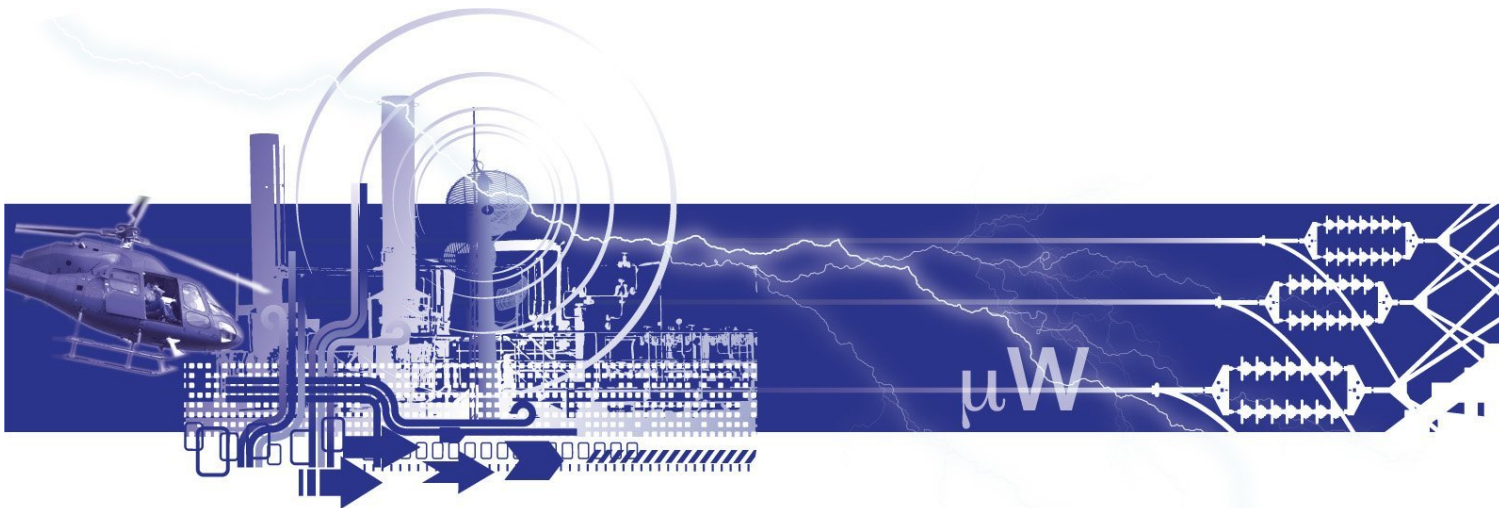


UNRESTRICTED REPORT

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Vphase plc



## Energy Saving Trial Report for the VPhase VX1 Domestic Voltage Optimisation Device

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VPhase VX1 Domestic Voltage  
Optimisation Device**

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# Energy Saving Trial Report for the VPhase VX1 Domestic Voltage Optimisation Device

by

Dr S.D. Wilson

## Summary

This report records the energy saving trial that was carried out for VPhase and Scottish and Southern Energy from September 2009 to May 2010, to determine the carbon saving that could be attributed to VX1 Domestic Voltage Optimisation Devices, if they were to be installed as part of a massed rollout in the UK.

Equipment was installed at fifty sites, each within the Reading and Newbury areas of Berkshire. This equipment measured energy consumption at the point of a domestic customer's connection to the electricity network, to high accuracy.

Sites were chosen based upon the requirement to obtain a spread of property types, locations and other demographics. The English House Condition Survey was used as the main reference point. The housing demographics of the survey were matched as closely as could be achieved.

Each chosen site received a VX1 Domestic Voltage Optimisation Device, which was installed by Scottish and Southern Energy, under the guidance of VPhase. Each site also received a monitoring installation, capable of recording up to three months of energy usage. The VX1 was configured to change between ON and OFF states nightly, so that differences in household energy consumption with the device ON and OFF could be computed.

The site selection process took much longer than anticipated, which led to some sites having much more data than envisaged in the Methodology. Over 2000 extra data-days were collected, above the minimum required by the Methodology. There were a couple of minor problems arising from time-switches, required to change the state of the VX1 device. While regrettable, these had little influence on overall results (and would not affect the operation of any VX1 devices which were not used for trials).

The data collected from all fifty sites was analysed by EA Technology, by the application of a number of energy saving algorithms. These were checked individually against a reference and between themselves to ensure that they estimated energy savings correctly. Overall,

we found that the percentage electrical energy saving attributable to VX1 devices, as part of any massed rollout, would equate to 5.2%. When re-based to non-electrically heated homes, these savings would equate to 6.3%.

The lifetime of the VX1 device was assessed as some 36 years, based upon assessments made by Relex and EA Technology and measurements made by the manufacturer.

The lifetime carbon abatement attributable to VX1 devices, as part of any massed rollout, is estimated as 5.0 tonnes CO<sub>2</sub> per household, over the estimated 36 year lifetime of the device, based upon the reference carbon emissions factor of 0.591 kgCO<sub>2</sub>/kWh derived from the Building Research Establishment's Standard Assessment Procedure.

EA Technology understands that a carbon score of 2.5 tonnes over a twenty year lifetime will currently apply to this measure, as decided by Ofgem, who have taken into consideration lifestyle changes and the continuing development and emergence of domestic voltage optimisation technologies.

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# 1 Introduction

This report contains EA Technology's assessment of the carbon abatement attributable to installations of the VPhase VX1 Domestic Voltage Optimisation Device, in Great Britain (GB) housing stock.

## 1.1 Distribution Network Voltage in Great Britain

The GB nominal voltage to households is 230V +10% -6%, which equates to a voltage range of 217V to 253V. There are several reasons why the voltage normally delivered to properties is greater than 240V: the GB nominal supply was 240V  $\pm$ 6% until 1995, power quality is generally better when networks are operated towards the top end of the allowable range and cables can be run further from substations when the source voltage is set higher.

For these reasons, the nominal voltage of many distribution substations in Great Britain is set to 253V. The voltage delivered to customers generally reduces as the distance from the substation increases (although the opposite situation can occur if there is generation in the vicinity).

In the context of this report, the term "utility supply voltage" is used. This refers to the voltage delivered by the electricity distribution network to the point of connection of the consumer. It is not to be confused with any utility companies, in the context of this report

The precise voltage delivered to customers depends on the network topology (meshed or radial), state of loading and the settings of any voltage-controlling equipment placed on the network. This results in constantly fluctuating voltages, and changes to average daily voltages, at all points on an electricity network.

Network running arrangements vary from region to region, depending not only on the policy of the network operator, but also on the topology and geography.

## 1.2 The VPhase VX1 Domestic Voltage Optimisation Device

The VX1 is a device which is connected to the utility voltage supply and which regulates its output voltage to 220V. The output of the device is connected to circuits within the home, which are then operated at 220V rather than the utility supply voltage. The benefit of using the VX1 to optimise the voltage delivered to appliances is that, it is claimed, the appliances will then consume less energy. The reasons and evidence for this statement will not be discussed here as they have been referenced and discussed in earlier trial correspondence.

The VX1 uses thermal management techniques and innovative design to provide high output capability in a relatively small unit. The device is able to ride-out short-term high power demands by allowing the temperatures of key components to rise for short periods. At a predefined temperature the device cuts itself out-of-circuit (referred to as 'bypass') in a controlled manner, enabling it to cool, returning to its active state when demand has reduced.

An example of this is the occasional use of several appliances at once –boiling a kettle at the same time as operating a washing-machine or tumble-dryer.

### 1.3 The Energy Saving Trial

VPhase and Scottish and Southern Energy (SSE) approached EA Technology with a request to independently monitor the energy saving of a number of domestic properties in which the VX1 device was to be installed. The aim was to provide information which can be used to set the level of carbon saving that could be expected from wide-scale adoption of the technology across Great Britain.

VPhase believe that, with suitable proof of energy savings, their device will be eligible as a Carbon Emissions Reduction Target (CERT) measure<sup>1</sup>. To be accepted as a valid CERT measure, these savings must be proved to the satisfaction of Ofgem.

EA Technology has extensive monitoring experience with residential field trials including micro-combined-heat-and-power, condensing boilers and heat pumps. This experience has been drawn upon in the selection of monitoring equipment for the trial and the analysis of its results.

In this report there are references to data sources which pertain to the UK rather than GB, to which CERT applies. This in no way impacts upon the conclusions of the report, in the GB-only context of CERT.

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<sup>1</sup> CERT runs from 2008-11 and obligates Energy Suppliers to meet carbon reduction targets, by means of schemes which deliver carbon reductions



## 2 The Trial Methodology

The aim of the trial is to evaluate the carbon saving of the VPhase VX1 Voltage Optimisation Device, on a per-house basis. The trial methodology was agreed in principle with Ofgem prior to commencement. One of the main considerations was that the VX1 would not make energy savings where closed-loop electric heating was in use. Houses where the main heat source was electric were to be excluded from the trial.

Fifty VX1 units were fitted with a modification which enabled them to be switched into or out of active mode. When not in the active mode, the device is effectively switched out-of-circuit, with the utility supply voltage being passed through a relay to the connected loads. No voltage optimisation occurs in this state.

When in the active state the VX1 regulates the voltage at its output to 220V. The trial methodology called for the VX1 to be switched between its active and inactive state on a daily basis. This provides a difference between days, which can be evaluated to determine energy savings. Switching was carried out nominally at 0100hrs each night, driven by a timer device. Particulars of the key information items in the trial are listed in Table 1:

**Table 1: Information Items in Methodology**

| Item                 | Formula        | Design Value     |
|----------------------|----------------|------------------|
| Monitoring Period    | Sites*Days     | 50*60 = 3000     |
| ON/Active Days       | Sites*Days/2   | 50*30 = 1500     |
| OFF/Inactive Days    | Sites*Days/2   | 50*30 = 1500     |
| Transitions (On/Off) | Sites*(Days-1) | 50*(60-1) = 2950 |

The different categories of information provide a hint as to different algorithms which can be used for analysis of energy savings. Several algorithms have been applied, which are discussed in Section 5.

Ofgem's CERT guidelines require the VX1 to be tested across a range of property locations, types, ages and customers. This is so that the results are applicable to rollout across GB.

Property age is considered to be important as it is an indication of the performance of thermal insulation and will have an influence on the amount of energy consumed in the property.

Property type/size affects energy consumption since larger properties may have more occupants and/or appliances.

Property location (city / suburbs / rural) is considered to have an impact on lifestyle and hence energy consumption.

The trial aimed to match the above factors against the demographics of the English House Condition Survey<sup>2</sup> as closely as possible, with the proviso that available sites were limited to the Reading and Newbury areas of the UK, to customers that agreed to participate in the energy saving trial and to those where electric heating was not in use. For thermostatically-controlled electric-heating devices, voltage optimisation equipment does not save energy

The key output of the trial is the lifetime carbon saving that should be attributed to any massed rollout of VX1 units across GB.

<sup>2</sup> Department for Communities and Local Government, English House Condition Survey 2007, September 2009.

The trial methodology has not changed since being agreed in principle with Ofgem. Section 6 describes an issue with one of the pieces of equipment used in the trial, which affected a few sites. At these sites, the VX1 device did not change from the ON to OFF state (and vice-versa) reliably each night.

### 3 Measuring Equipment

Measuring equipment is required to perform three fundamental tasks:

- 1) Measure and record the energy consumption of the property on a daily basis
- 2) Verify the operation state of the VX1 unit
- 3) Record data for a minimum of 60 days

To accomplish the energy measurement, a fiscal quality electricity meter<sup>3</sup> was fitted at each property, which measured whole-house electricity consumption. The meters produce a pulse output – set at 1 pulse per Wh – which could be counted and recorded by a data-logger. The pulse output rate selected is higher than that used in standard metering, allowing the electricity consumption to be measured to a high degree of resolution.

Electrical energy consumption was measured at 10-minute intervals, one day consisting of 144 intervals. This provided an increased level of detail, which was judged as being advantageous for the identification of faults, possible use of electric heating and enhanced precision in the analysis of energy savings.

To verify the operation state of the VX1 unit, the distribution network supply voltage and VX1 output voltage were measured to an accuracy of  $\pm 1.0\%$ , using “IME TM2U” voltage transducers<sup>4</sup>.

Recording of energy and voltage measurements was performed by “Novus Logbox” instruments. These provided the capability to record a minimum of 3 months data at each site.

Monitoring equipment was built into kits for installation at each site, see Appendix 1 for further details.

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<sup>3</sup> AMPY Type 5235B

<sup>4</sup> Datasheet available from [www.rayleigh.co.uk](http://www.rayleigh.co.uk), accessed September 2009

## 4 Sites in the Trial

The methodology called for an evaluation across 50 sites. The fifty were to be chosen based on the Selection Factors listed in Table 2. Clearly, trial participants must be willing volunteers in order that installation and data collection tasks can be carried out effectively. The second factor is electric heating, which to comply with the methodology, should not be present. In practice, some sites with supplementary electric heating were included. See Section 4.6 for details.

The third selection factor was the suitability of the site for VX1 installation: was enough space available for the unit, was the property electrical wiring safe for installation to take place or did complicated supply arrangements exist which would make it difficult to measure electricity consumption?

**Table 2: Selection Factors**

| Priority | Selection Factor                 | Factor Levels                                   | Method of Assessment   |
|----------|----------------------------------|---|--|
| 1        | Willing to Participate           | Yes/No  | Questionnaire Responses  |
| 2        | Electric heating not in use      | Yes/No  | Questionnaire Responses  |
| 3        | Suitability for VX1 Installation | Pass/Fail                                       | Site Survey by Southern Electric Contracting (SEC) Personnel <sup>5</sup>                              |
| 4        | Property Type                    | Bungalow<br>Terrace<br>Semi<br>Detached<br>Flat | Questionnaire Responses  |
| 5        | Property Age                     | Construction Decades                            | Questionnaire Responses  |
| 6        | Location                         | City<br>Town<br>Suburbs<br>Rural                | Postcodes and CAMEO <sup>6</sup><br>Location Statistics (the use of CAMEO is described in Section 4.4) |
| 7        | Distance from Substation         | Metres from Distribution Substation             | Study by SSE Personnel   |

SSE implemented a call-centre process and team to handle customer responses and queries. In excess of 300 potential sites were investigated for use in the trial. The nature of housing in the Reading and Newbury areas was, however, such that it was difficult to make a good approximation to the English House Condition Survey demographics. Priority was therefore assigned to selection factors in the order presented in Table 2.

The justification for this order is that yearly electrical energy consumption and voltage are the main factors governing the carbon abatement potential of the VX1. "Distance from Substation" is a proxy-factor for the magnitude of voltage delivered to properties. This distance defines much of the reduction in property voltage caused when networks are loaded. However it is not a particularly good indicator of property voltage, since other voltage-controlling equipment exists on networks and this is one of the reasons that utility supply voltage was monitored at each property. Therefore, "Distance from Substation" was not considered to be as important a selection factor as those of Property Type, Age and Location. Monitoring of the average utility voltage at trial sites proved the average utility

<sup>5</sup> SEC is a division of SSE

<sup>6</sup> Further information available at <http://www.callcreditmarketing.com/pages/consumer-targeting-solutions>, accessed 18/08/2010

voltage to be 245V, an exact match against the average utility voltage provided to VPhase by the Energy Networks Association<sup>7</sup>.

Electrical energy consumption at the trial sites was calculated to be 4590kWh/year on a yearly average basis, close to 2008 UK average domestic energy consumption of 4478kWh<sup>8</sup>.

## 4.1 The English House Condition Survey (EHCS)

The EHCS is a comprehensive survey carried out for the Department for Communities and Local Government by the Office for National Statistics (ONS), Building Research Establishment (BRE) and others. It reports yearly on the standard and composition of English housing stock. 2007 statistics were available at the time of site selection and were used to define the 'ideal' selection of trial sites, in terms of the selection factors listed in Table 2.

## 4.2 Property Types

Table 3 lists: the types of property in the EHCS, the number of each which would be required for the trial to match the EHCS exactly, a simplified breakdown of property types for the trial and the numbers achieved. Actual property type was assessed by householders in conversation with SSE's customer service team.

**Table 3: Trial Property Types**

| EHCS Property Type | EHCS Number | Trial Property Type | EHCS Number | Achieved |
|--------------------|-------------|---------------------|-------------|----------|
| Small terrace      | 5           | Terraces            | 14          | 13       |
| Large terrace      | 9           | Semi                | 14          | 16       |
| Semi               | 14          | Detached            | 9           | 16       |
| Detached           | 9           | Bungalow            | 5           | 2        |
| Bungalow           | 5           | Flats               | 8           | 2        |
| Converted flat     | 2           | Unknown             |             | 1        |
| Low rise flat      | 6           | <b>Total</b>        | 50          | 50       |
| High rise flat     | 0           |                     |             |          |
| <b>Total</b>       | 50          |                     |             |          |

Housing areas were predominantly suburban, which resulted in an abundance of larger properties being available and very few flats or terraces. Every single flat and terrace that passed the VX1 installation criteria was included in the trial, however the trial was still underweight in those types of property.

The quantities of properties of different types, ideal and achieved, are presented in Figure 1. There was a shortfall in the numbers of smaller properties (Terraces & Flats) required to meet the ideal composition. However, as noted earlier, we found that the average energy consumption of the trial as a whole was no less than 2008 UK national averages. Considering this fact, we conclude that the achieved numbers of properties of different types were appropriate for the trial.

<sup>7</sup> As previously submitted by VPhase in documents to Ofgem, prior to the trial

<sup>8</sup> DECC, Electricity consumption at regional and local authority level 2008, available at [www.decc.gov.uk](http://www.decc.gov.uk), accessed 31/03/2010. Value is a UK average and includes electrically-heated properties.

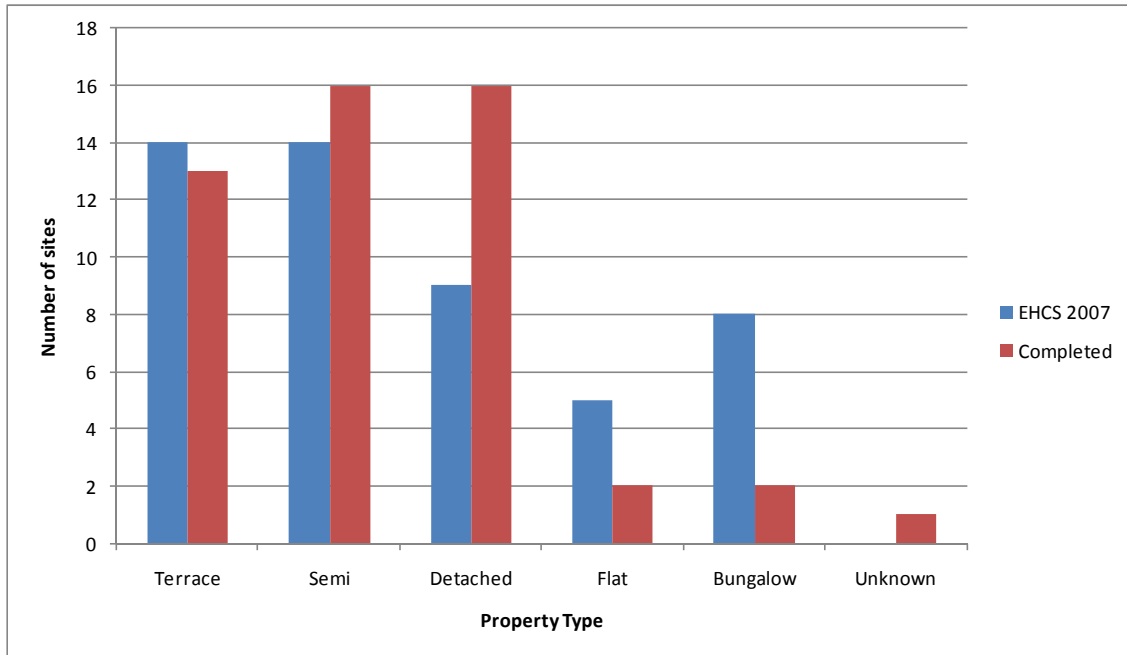


Figure 1: Trial Property Types

### 4.3 Property Age

Property age was assessed by SSE's customer service team in conversation with householders. The year of first construction was taken to compare against EHCS statistics. EHCS statistics indicated that a 50-site trial would ideally contain the numbers of properties listed in Table 4, where the number achieved is also listed.

Table 4: Trial Property Ages

| Year of Construction | EHCS Number | Achieved  |
|----------------------|-------------|-----------|
| 1800-1899            | 0           | 4         |
| 1900-1909            | 0           | 0         |
| 1910-1919            | 3           | 1         |
| 1920-1929            | 4           | 4         |
| 1930-1939            | 4           | 3         |
| 1940-1949            | 5           | 0         |
| 1950-1959            | 5           | 7         |
| 1960-1969            | 8           | 10        |
| 1970-1979            | 8           | 7         |
| 1980-1989            | 6           | 7         |
| 1990-1999            | 4           | 3         |
| 2000-2009            | 3           | 2         |
| Unknown              |             | 2         |
| <b>Total</b>         | <b>50</b>   | <b>50</b> |

Table 4 values are also presented in Figure 2. There were more of the pre-1800 homes than ideal, whilst less of modern, post-1990 construction. The age profiles are similar.

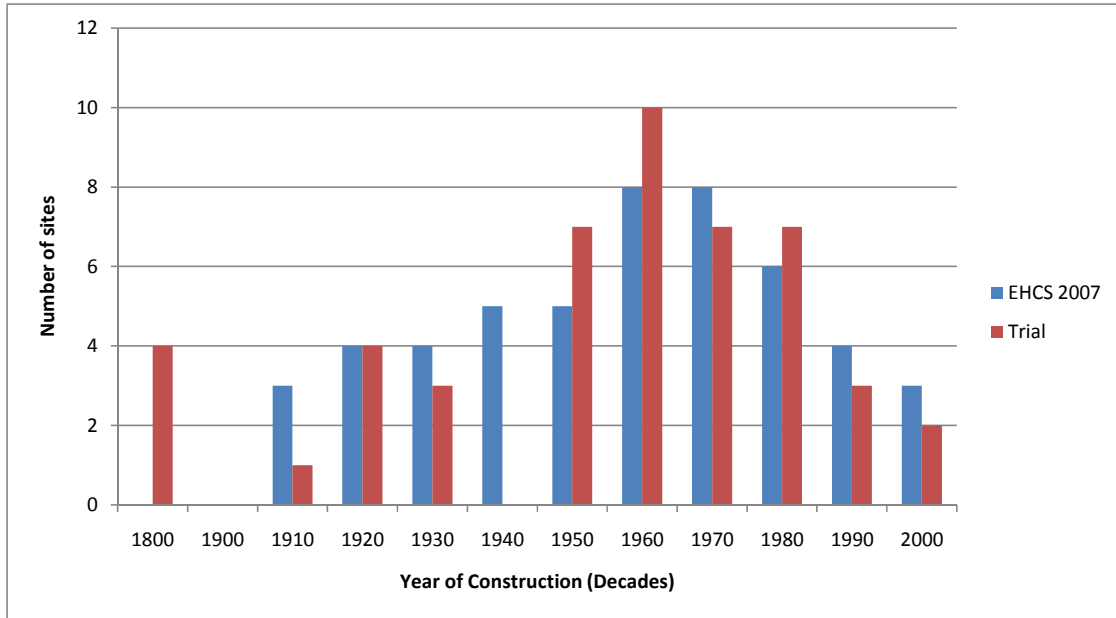


Figure 2: Trial Site Property Age

#### 4.4 Property Location

Property location was determined using the CAMEO system used by SSE. The input to CAMEO is the property postcode. The CAMEO system then classifies that postcode in terms of a number of population demographic parameters, yielding a single descriptor. These descriptors were then passed to EA Technology. EA Technology then compared the descriptors against a table of descriptor-demographics to determine trial site locations.

Property location is classified in CAMEO as: City/Suburbs, Town/Suburbs, Suburbs/Rural, Rural or Suburbs.

Property location is classified in the EHCS as being: City Centre, Other Urban Centre, Suburban, Rural Residential, Village Centre or Isolated Rural.

To compare the two sources, so that houses can be selected for the trial using the CAMEO, system, a pseudo-location metric must be used. City, Town, Suburbs and Rural were chosen as the levels of the location factor, with the numbers of sites in each pseudo-location (denoted EHCS') being determined according to the following:

EHCS' City = EHCS City Centre

EHCS' Town = EHCS Other Urban Centre + 0.5\*EHCS Village Centre

EHCS' Suburbs = EHCS Suburban

EHCS' Rural = EHCS Isolated Rural + 0.5\* EHCS Rural Residential + EHCS Village Centre.

Table 5 presents the results of this metric.

**Table 5: EHCS Property Locations**

|                      | <b>EHCS</b> |   | <b>EHCS'<br/>(Ideal Trial)</b> |
|----------------------|-------------|---|--------------------------------|
| City Centre          | 2           |   | City                           |
| Other Urban centre   | 17          |   | Town                           |
| Suburban Residential | 13          | → | Suburbs                        |
| Rural Residential    | 11          |   | Rural                          |
| Village Centre       | 4           |   |                                |
| Isolated Rural       | 3           |   |                                |
| <b>Total</b>         | <b>50</b>   |   | <b>Total</b>                   |
|                      |             |   | <b>50</b>                      |

For the trial properties, the numbers of sites in each pseudo-location (denoted CAMEO') was determined according to the following:

CAMEO' City = 0.5\*CAMEO City/Suburbs

CAMEO' Town = 0.5\* CAMEO Town/Suburbs

CAMEO' Suburbs = 0.5\* CAMEO City/Suburbs + 0.5\* CAMEO Town/Suburbs + 0.5\*  
CAMEO Suburbs/Rural + CAMEO Suburbs

CAMEO' Rural = CAMEO Rural

Table 6 presents the results of this metric.

**Table 6: Trial (CAMEO Derived) Property Locations**

|               | <b>CAMEO</b> |   | <b>CAMEO'<br/>(Achieved)</b> |
|---------------|--------------|---|------------------------------|
| City/Suburbs  | 0            |   | City                         |
| Town/Suburbs  | 11           |   | Town                         |
| Suburbs/Rural | 33           | → | Suburbs                      |
| Rural         | 1            |   | Rural                        |
| Suburbs       | 3            |   | Unknown                      |
| Unknown       | 2            |   |                              |
| <b>Total</b>  | <b>50</b>    |   | <b>Total</b>                 |
|               |              |   | <b>50</b>                    |

The numbers of sites achieved in each location (CAMEO') and the ideal numbers (EHCS') are compared in Figure 3. There was a bias towards less densely occupied areas, which is in common with the housing environment around Reading and Newbury. Attempts were made to increase the numbers of properties in City and Town locations, but these did not yield many properties with which to improve the selection.



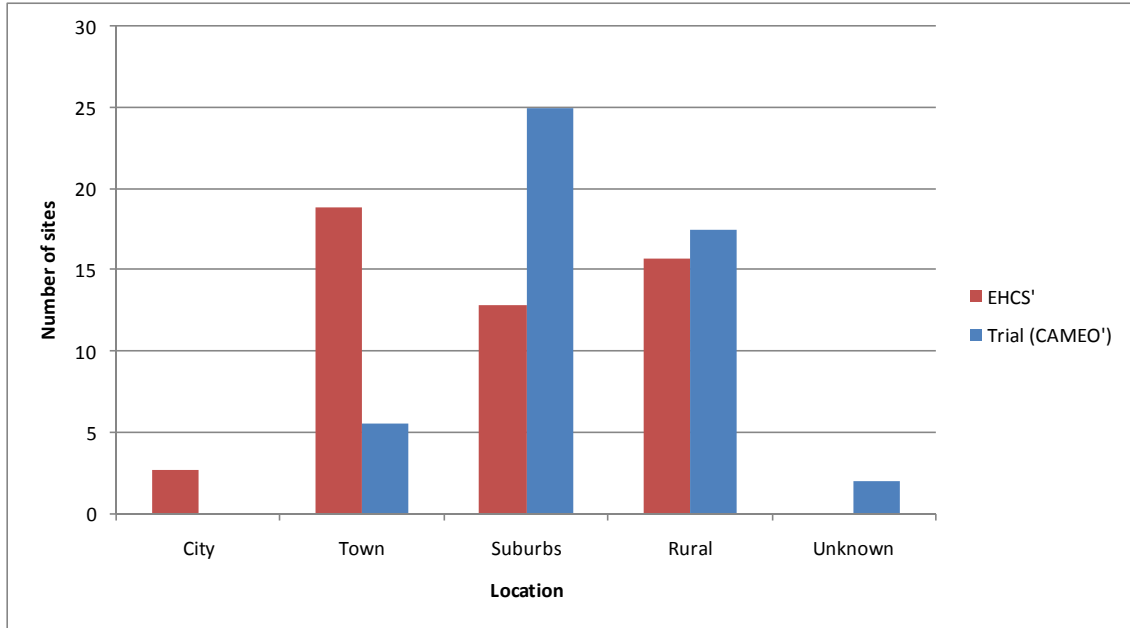


Figure 3: Trial Site Locations

### 4.5 Distance from Substation

Distance from substation was assessed by SSE personnel using property postcodes and by locating substations using mapping data. As noted, the purpose of monitoring the distance from substation was to guard against selection bias towards higher or lower voltages. The distribution of substation distances, obtained before the trial commenced, presented in Figure 4, did not have a notable bias towards very long or very short distances. Utility voltage data collected from sites during the trial proved that the average voltage across all sites was 245V, which was equal to that stated to VPhase by the Energy Networks Association.

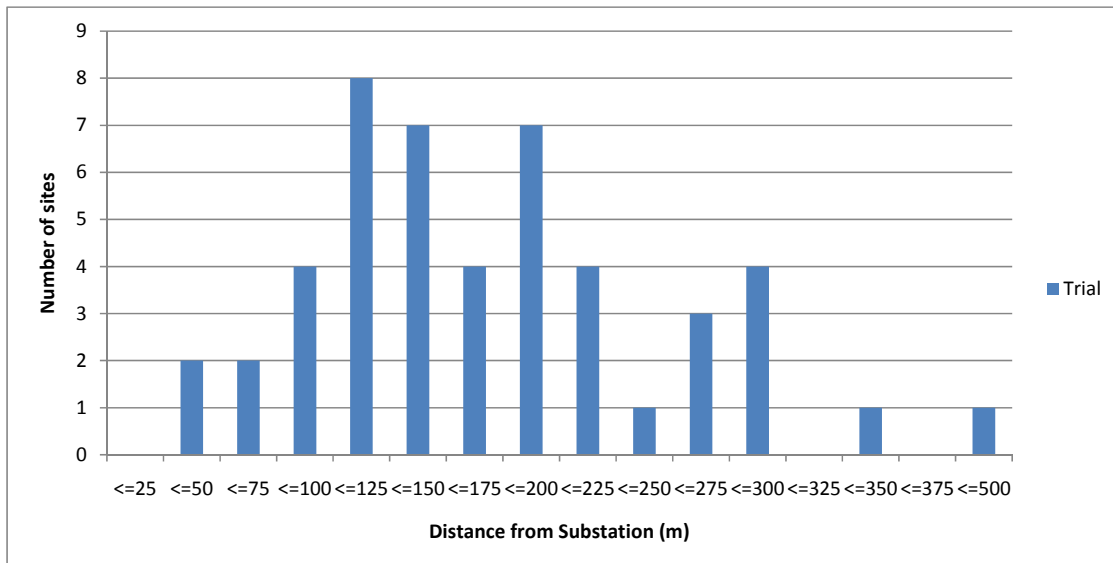
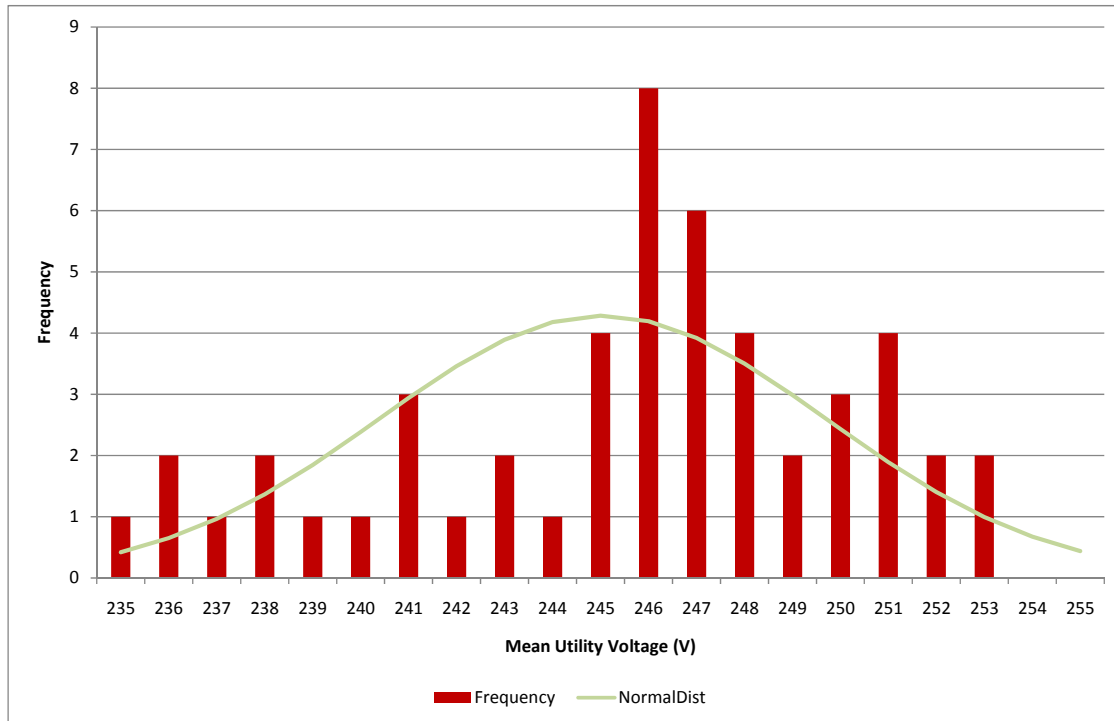


Figure 4: Trial Sites' Distances from Substations

The distribution of mean utility voltage is presented in Figure 5, which showed the mean utility voltage at sites to range between 235-253V. In general, those properties which were most distant from substations will have the lowest supply voltages (i.e. when comparing Figure 5 to Figure 4, the x-axis of Figure 5 should be reversed).

Intra-day deviation in voltage was generally small compared to the difference between utility supply voltage and the voltage set-point of the VX1 device (220V). See Section 2 of Appendix 5 for time-of-day profiled intra-day deviations at a sample of 3 sites.



**Figure 5: Trial Sites Mean Utility Voltage**

## 4.6 Electric Heating

One of the main selection factors for the trial was that electric heating should not be in use. However during the site selection process, this was taken to mean that the 'main heat source' should not be electric. A number of sites were selected where electric heating was in use for cooking, showers and/or water heating. These sites were retained in the trial and analysed, however VPhase requested that a piece of work establish what the percentage energy saving would have been if electric heating had not been present. This is included in Appendix 10.

## 5 Analysis of Electrical Energy Saving

The main output of this trial is the lifetime carbon saving that could be attributed to any massed rollout of VX1 devices in the UK.

Electrical energy consumption and voltage data was collected at all fifty sites. VX1 units and measuring equipment were installed for between 60 and 170 days, depending on the site. This was in agreement with the methodology, which stated that a minimum of 60 days of data would be collected for each site. The reason for more than 60-days being available is that the site selection process took longer than anticipated. The first sites had equipment installed in September 2009, whilst the last sites had equipment installed in March 2010.

To understand the analysis contained in this Section, the reader must note that the energy saving attributable to the VX1 device cannot be measured directly. The electrical energy consumption of each site/property has been measured. The inhabitants of each site determine how much electrical energy they use each day and how the consumption varies throughout each day, through their normal behaviour. Their consumption pattern changes from day to day in response to the type of food being prepared, washing habits, television schedules, work patterns, leisure activities etc.

These changes create uncertainty in estimated energy savings. This uncertainty must be quantified in order to ensure that the significance of results is correctly understood.

### 5.1 The Origin of Uncertainty in Energy Savings

The VX1 unit was operated in a day-ON, day-OFF mode. Given that the amount of energy consumed in any given time period is subject to variability, measurements of energy consumption in the ON and OFF states, considered in separate sets, provide no information about the energy saving. It is the difference between these sets that is required. Whenever the difference is computed, the true energy saving is confounded with natural variations in energy consumption. Given an infinite number of measurements, these natural variations would tend towards zero and the energy saving would be equal to the difference between mean energy consumption in the ON and OFF sets of measurements.

As time and effort is always limited, the number of measurements is inevitably finite and any calculation of energy saving will have a degree of uncertainty associated with it. This reduces as the number of available measurements (and the monitoring period) increase.

We have implemented a number of algorithms which estimate the true energy saving and determine uncertainty in the form of confidence limits.

### 5.2 Energy Saving Algorithms

For the vast majority of sites, the results we present in Section 6 are derived from a single algorithm, which we believe makes fullest use of the information available from the trial. We have, however, implemented a number of additional algorithms. We have chosen to use these as fallback options and to assist in the identification of any errors.

These and a series of tests performed with the algorithms, are described in the following Sections.

### 5.2.1 Common to all algorithms

All algorithms allow for the energy consumption of the VX1 unit (the measurement of which is presented in Appendix 3), which has the effect of making the energy consumption on VX1 OFF days being slightly higher than if there was no VX1 device installed.

All algorithms are applied to a selection of the available monitoring data. This is generally the whole monitoring period, minus any partial days at the start and end of the period. It has been noticed that step changes in load (such as the start of a holiday or other atypical change to a property's base load) can unduly affect the results of algorithms. This is because the true energy saving is best estimated by any algorithm, when the underlying energy consumption pattern does not change. Hence if there has been a step change in load towards the beginning or end of a monitoring period, we have adjusted the analysis window to exclude it. Holidays during monitoring periods have been left in the analysis except where we have judged these to be excessive. Notes on these are included in the tables of analysis results in Appendix 4.

Where confidence limits are calculated, these have been made to a confidence level of 95%.

The examples in these sections are made using the data from Site 1, for which 65 days of data were included in the monitoring window, where there were a few short holidays in evidence and where the VX1 unit changed state between ON and OFF each night.

We will now discuss each algorithm in turn, in the order of preference that we have used for our analysis.

### 5.2.2 Algorithm 4

*Short Description: mean differences evaluated on ON/OFF state changes, for 10-minute periods, across days.*

This algorithm computes the difference in energy consumption in each 10-minute period, between the current day and the previous day, provided that there has been a transition between the ON and OFF states of the VX1 unit. The mean difference in energy consumption is computed for each of the 144 10-minute periods in a day.

Next, the sum and standard deviation of the differences is calculated across all the days in the monitoring period. The per-site percentage energy saving is the sum of the differences divided by the mean energy consumption evaluated on the OFF days only.

The per-site confidence limit for this algorithm is computed using the standard deviation of the 144-strong population of 10-minute periods.

The algorithm does not attempt to normalise for the numbers of each day of the week that fell in the monitoring period. It is our preferred algorithm since it takes account of consumption profiles, producing tighter confidence limits than Algorithm 3.

By way of example, for Site 1, Algorithm 4 estimated the energy saving as 3.8%  $\pm$ 4.4%.

### 5.2.3 Algorithm 3

*Short Description: mean differences evaluated on ON/OFF state-changes, for daily periods, across days.*

This algorithm computes the difference in daily energy consumption between the current day and the previous day, provided that there has been a transition between the ON and OFF states of the VX1 unit. The mean change in consumption across all the days in the monitoring period is calculated. The per-site percentage energy saving is the mean change in consumption divided by the mean energy consumption evaluated on the OFF days only.

The per-site confidence limit for this algorithm is computed by using the combined standard deviation of the ON group of changes and the OFF group of changes.

The algorithm does not attempt to normalise for the numbers of each day of the week that fell in the monitoring period.

By way of example, for Site 1, Algorithm 3 estimated the energy saving as 3.1%  $\pm$ 6.2%.

### 5.2.4 Algorithm 2

*Short Description: difference between mean energy consumption on ON and OFF days, for each day of the week, normalised for the numbers of each day of the week in the monitoring period.*

This algorithm computes the difference between mean daily energy consumption on ON days and OFF days. This is undertaken for each day of the week, with the numbers of each ON and OFF day experienced on each noted. A week is then constructed using the mean difference in energy consumption for each day of the week.

Due to complexity, a per-site confidence limit has not been calculated for this algorithm. However it is assumed that it will be similar to Algorithm 3, since the main source of variability is the difference in daily energy consumption, measurements of which are the input to the algorithm.

By way of example, for Site 1, Algorithm 2 estimated the energy saving as 2.9%.

### 5.2.5 Algorithm 1

*Short Description: difference in mean energy consumption for 10-minute ON periods and 10-minute OFF periods, across whole monitoring period.*

This algorithm is a quick and simple check which we have used for the elimination of errors in the other algorithms. No per-site confidence limit has been calculated.

By way of example, for Site 1, Algorithm 1 estimated the energy saving as 2.9%.

## 5.3 Robustness Tests of the Energy Saving Algorithms

Development of a series of algorithms of varying complexity and methodology provides a means of identifying errors in algorithms and coping with unforeseen problems with input data. However, comparisons between algorithms cannot identify so-called bias errors, which could be common to all algorithms. Possible manifestations of bias errors could, for example, cause results for sites to be plus 1% or minus 1% of the true energy saving.

To prove that any bias errors which may exist are not significant, we performed a series of robustness tests on our algorithms, designed to identify bias errors and to examine the effects of changes in load and any holidays which may occur within monitoring periods.

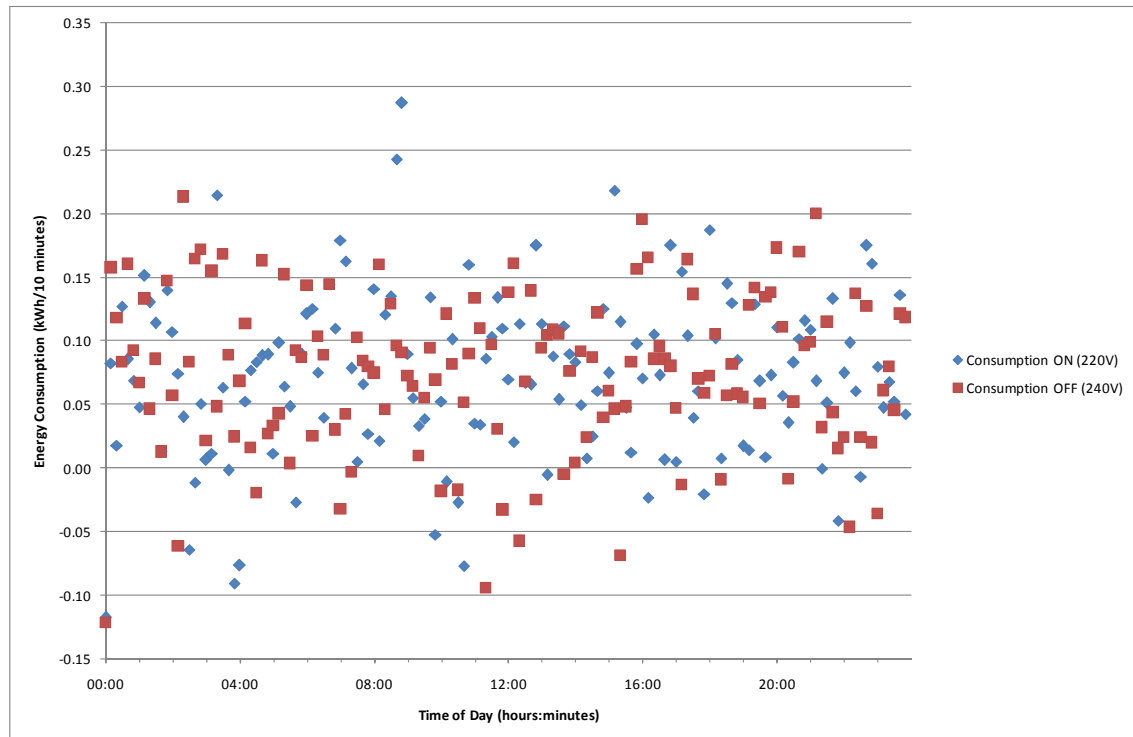
The main input for this task was a computer-generated pseudo-measurement set, the general parameters of which are listed in Table 7:

**Table 7: Parameter Values for Pseudo-Measurements**

| Parameter   | Value    |
|---|----------|
| Monitoring Period   | 66 days  |
| Energy Saving Percentage  | 5%       |
| Yearly Energy Consumption   | 4000kWh  |
| Standard Deviation of 10-Minute<br>Periods of Energy Measurements | 0.066kWh |
| VX1 Standby Load  | 66Wh/day |
| Toggling  | Nightly  |

The monitoring period was set to slightly longer than the minimum 60 days required for each site and the energy saving set subjectively, to 5%. Yearly energy consumption was selected as 4000kWh, slightly less than UK average. The standard deviation of the measurement set was set to be equal to that measured at Site 1. The standby load of the VX1 was set to that measured by EA Technology (See Appendix 3).

The pseudo-measurement set consisted of 66 days which alternated between ON and OFF energy consumption profiles. The same ON/OFF profile was used for each ON/OFF day. Figure 6 presents these ON/OFF profiles for the parameters listed in Table 7.



**Figure 6: Indicative Consumption Profile for Robustness Tests**

The profiles consist of a mean consumption level, around which data points are placed according to the specified standard deviation. It cannot be seen from study of Figure 6, but there is a 5% difference in consumption between the two profiles.

To evaluate whether the algorithms are affected by bias errors, the standard deviation and VX1 standby load parameters were set to zero, meaning that consumption was constant during ON and OFF days, with the difference in consumption being the true energy saving.

Algorithms 4 and 2 estimated the energy saving as 5.0%.

Algorithms 3 and 1 estimated the energy saving as 5.3%.

Thus there appears to be a small bias error affecting Algorithms 3 and 1. A selection of further tests were also run:

- 1) Second Set of Bias Tests (with the standard deviation set to the value in Table 7, four tests with different random-number seeds for the generation of variation)
- 2) Load Change Tests (a study of the effect of seasonally changing loads within the monitoring period)
- 3) Holiday Test (a study of the effect of a holiday within the monitoring period)

Short descriptions and results of all robustness tests are included in Appendix 2. We found from these further tests that Algorithm 2 could be affected by holiday periods and that Algorithm 1 tended to produce variable results when the standard deviation of measurements was set to the measured value listed in Table 7.

## 5.4 Selection of Preferred Algorithm

Our view is that overall, the tests described in Section 5.3 and Appendix 2 justify the use of Algorithm 4 as our preferred energy saving algorithm, with Algorithms 3, 2 & 1 being used as fallback options in that order of preference.

## 6 Electrical Energy Saving Results

These results have been calculated according to the analysis procedure described in the previous Section. Individual site results are included in Appendix 4.

### 6.1 Data Acquired

Greater than 60 days of data was acquired for the vast majority of sites. At some sites, a type of programmable timer caused problems, as it did not correctly instruct the VX1 device to change state between ON and OFF. At these sites, the following two symptoms were discovered:

1. Some data-downloads revealed that ON/OFF state changes had not occurred, hence less state-changes were retrieved than expected
2. State changes did not occur every night, but at intervals of two to three nights, hence less state-changes were retrieved than expected

At two of these sites we deemed it necessary to use the backup algorithms described in the previous Section, as our preferred algorithm did not appear to respond correctly. These Sites are listed in Section 6.2 below.

For the Methodology agreed with Ofgem, a minimum of 2,950 days of data were to be acquired across the 50 sites. Due to the staggered process of installation at sites, over 5100 days of suitable data were actually acquired (see Appendix 4, Individual Site Results). The effect of these extra days will have been to increase confidence in per-site energy saving results.

### 6.2 Sites Requiring Treatments

Five sites were excluded from the analysis due to installation reasons – either significant loads were not connected to the VX1 unit or there were other site-specific reasons that meant acquired data was not a fair record of the performance of the VX1 device. At two sites fallback algorithms were used. These sites are listed in Table 8, further notes being included in Appendix 4:

**Table 8: Sites Requiring Treatment**

| Treatment                      | Site Ref. | Reason   |
|--------------------------------|-----------|--|
| Exclude Site from Mean Results | 13        | Central heating not connected <sup>9</sup>                   |
|                                | 24        | Garage, freezer and pond pumps not connected                 |
|                                | 26        | Two consumer units, only one connected to VX1, unknown loads |
|                                | 39        | Garage circuits not connected                                |
|                                | 54        | Central heating not connected                                |
| Fallback Algorithm             | 6         | Algorithm 2, Missing data                                    |
|                                | 21        | Algorithm 2, Irregular toggling                              |

<sup>9</sup> Central heating comprises load including pumps and fans, on which VPhase expect significant savings



### 6.3 Outlier Treatment

Given the wide spread of per-site percentage energy savings, we do not consider there to be a statistical case for the identification and removal of outliers. By 'outliers' we mean sites with percentage energy savings which are at the extremities of the results set.

### 6.4 Energy Consumption and Voltage Statistics

Table 9 details statistical parameters of the trial sites in terms of mean utility voltage<sup>10</sup> and estimated yearly energy consumption.

**Table 9: Energy Consumption and Voltage Statistics**

|  | Mean Utility Voltage (V) | Energy Consumption (kWh/year) |
|--|--------------------------|-------------------------------|
| <b>Max</b>   | 253                      | 12200                         |
| <b>Mean</b>  | 245                      | 4590                          |
| <b>Min</b>   | 235                      | 1320                          |
| <b>Standard Deviation (across sites)</b>                         | 5                        | 2360                          |
| <b>Confidence Limit on Mean (<math>\pm</math>, across sites)</b> | 1                        | 654                           |

Mean utility voltage was determined to be  $245 \pm 1V$ , with the maximum voltage being 253V and the minimum being 235V. Mean energy consumption was determined as  $4590 \pm 654kWh/year$ , with the maximum being 12200kWh/year and the minimum being 1320kWh/year.

Distributions of energy consumption and mean utility voltage are included in Appendix 5.

### 6.5 Trial Mean Energy Saving (as Percentage of Whole-House Electricity Consumption)

The mean electrical energy saving on whole-house electricity consumption, for each of the algorithms, for the 45 included sites is presented in Table 10. Note that the selection of trial properties included some electric heating appliances, as discussed in Appendix 10. Voltage optimisation does not realise energy savings for thermostatically-controlled electric heating appliances.

The algorithms determine the mean electrical energy saving as being between 4.6% and 5.3%. In the Analysis Section, we stated that Algorithm 4 is our preferred energy saving algorithm, at two sites listed in Table 8, fallback algorithms were required to be used. The "Treated" column in Table 10 presents the mean electrical energy saving, taking account of the fallback algorithms at these sites.

The mean percentage electrical energy saving is 5.2%, determined to confidence limits of  $\pm 1.4\%$ . This 5.2% mean value is used in all subsequent calculations.

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<sup>10</sup> Calculated as the mean utility supply voltage averaged across the whole analysis window

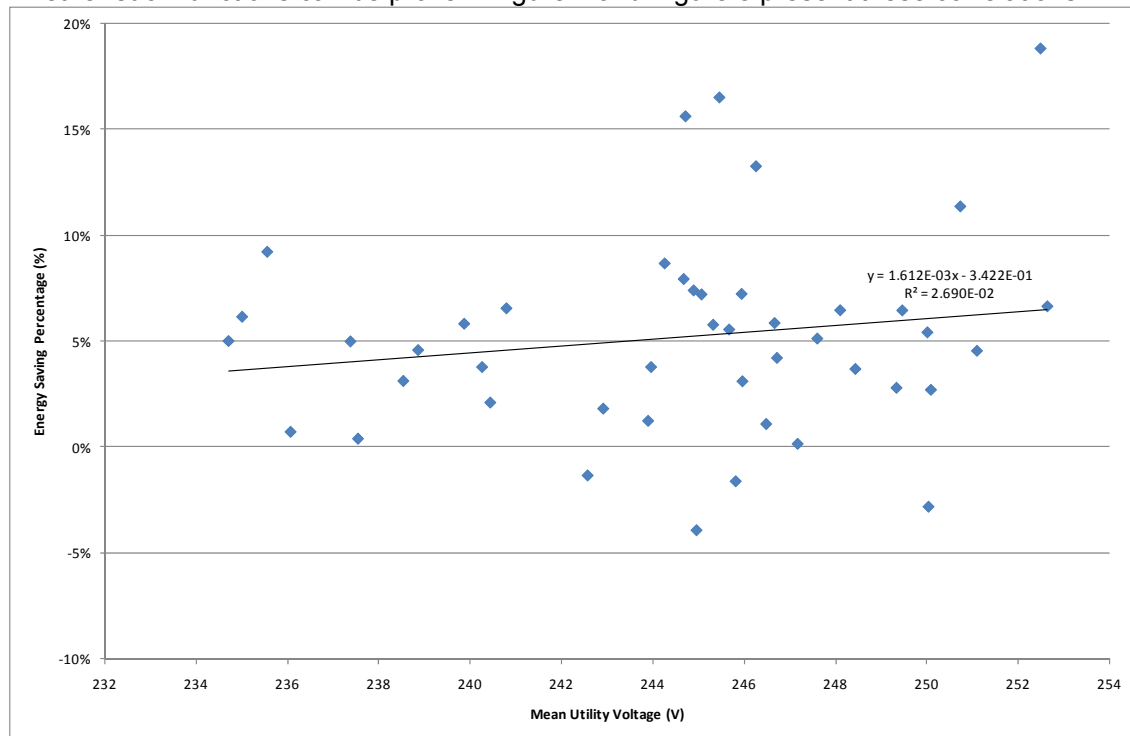
**Table 10: Electrical Energy Saving Results**

| Parameter   | Algorithm 4 | Algorithm 3 | Algorithm 2 | Algorithm 1 | Treated     |
|---|-------------|-------------|-------------|-------------|-------------|
| Mean Electricity Saving (%)                           | 5.0%        | 5.0%        | 4.6%        | 5.3%        | <b>5.2%</b> |
| Number of Sites in Algorithm                          | 45          | 45          | 45          | 45          | <b>45</b>   |
| Standard Deviation of Energy Saving (%) <sup>11</sup> | 5%          | 5%          | 5%          | 5%          | <b>5%</b>   |
| Confidence Limit on Mean $\pm$ (%) <sup>11</sup>      | 1.4%        | 1.4%        | 1.3%        | 1.6%        | <b>1.4%</b> |

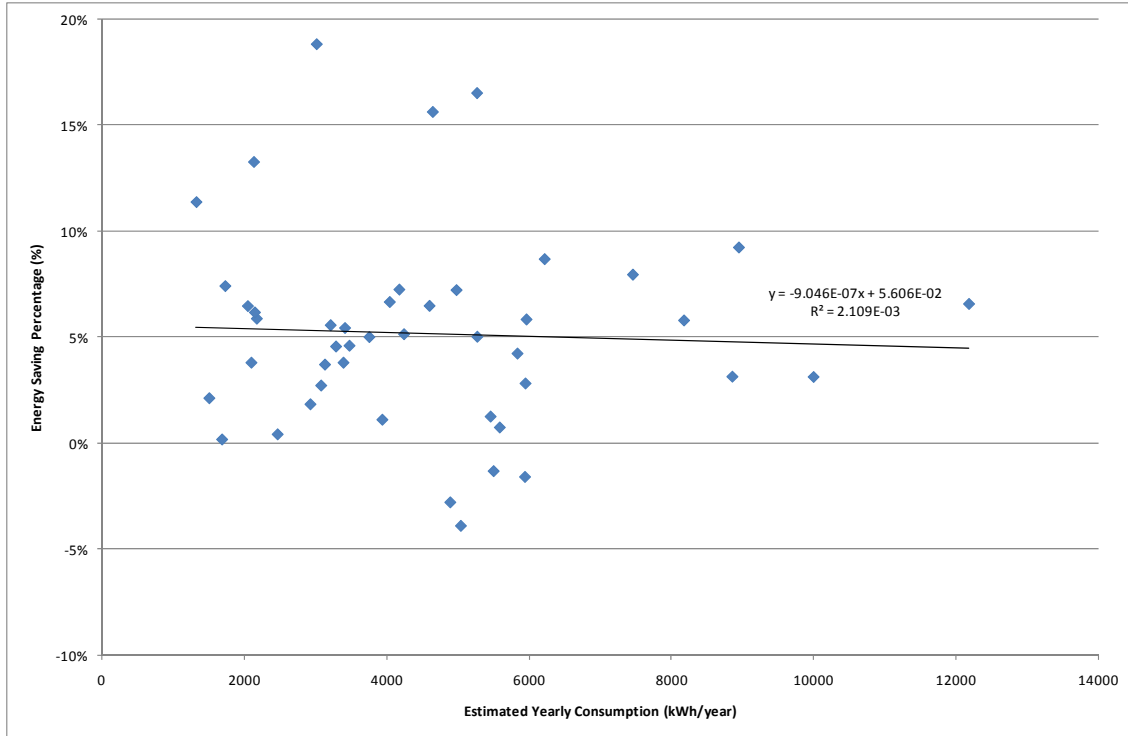
Distributions of energy saving percentages for individual sites are included for the interested reader in Appendix 5. Appendix 5 also contains details of typical energy demand and supply voltage profiles, at three sites. These have been chosen according to their supply voltage: low, medium and high. At these sites, the voltage profiles delivered by the VX1 were similar. Supply voltage profiles varied between sites and consumption profiles were significantly different between sites.

## 6.6 Energy Saving Correlation with Utility Voltage and Energy Consumption

The energy saving of the VX1 device is believed to be a function of utility voltage and of the magnitude of energy consumption. Data from the trial has been studied to determine whether such functions can be proven. Figure 7 and Figure 8 present these correlations.

**Figure 7: Correlation of Energy Saving Percentage with Mean Utility Voltage**

<sup>11</sup> Standard deviations and confidence limits are expressed as percentage energy savings



**Figure 8: Correlation of Energy Saving Percentage with Estimated Yearly Consumption**

In both cases, the correlation is weakly determined. Less than 1% of the deviation in the energy saving percentages can be represented in terms of a linear function of either mean utility voltage or consumption. This should not be considered as proof that such correlations do not exist, rather that they cannot be determined to any significant level of confidence, given the wide spread of energy saving results from the trial.

## 7 Carbon Saving Potential

As mentioned in Section 2, Methodology, the key output from the study is the lifetime carbon saving attributable to the VX1 device. This depends on three factors: the lifetime of the device, the duration of the carbon saving and the carbon emissions factor of electricity. This Section covers each of the three areas, ending with an assessment of the lifetime carbon abatement.

Subsections 7.1 and 7.2 cover the lifetime of the VX1, with information from Relex Software Corporation Consulting Division (Relex)<sup>12</sup>, VPhase and EA Technology.

Subsection 7.3 covers the carbon emissions factor.

Subsection 7.4 covers the assessment of lifetime carbon abatement.

### 7.1 Relex and VPhase Reliability Reports

Relex employed a computer reliability program which predicts the failure rate of the VX1 device as a function of temperature and stress, evaluated for each component of the VX1. The Relex report is included in Appendix 6.

Relex predicted the mean-time between failure to be 51 years, however this is based on a temperature rise of components of 20K above ambient air temperature. The significance of this is that the VX1 is contained within an enclosure, the air within the enclosure being heated by losses to a higher than ambient temperature.

To take account of this and of a small number of component changes made to pass Electro-Magnetic Compatibility (EMC) compliance tests, VPhase have provided a report. This is included in Appendix 7 and details:

1. The test method employed to determine the temperature inside the VX1 enclosure
2. Component changes for EMC compliance
3. Effects on the predicted lifetime of the unit

VPhase predict the lifetime based on application of the highest temperature measured inside the enclosure, to be 26.6 years and recommend use of this value for carbon calculations.

VPhase predict the lifetime based on the temperature towards the middle of the control board to be 38.1 years.

EA Technology's view is that 26.6 years is conservative. We note the following in relation to the predicted lifetime of the device:

1. In the Relex report, confidence levels were set to 60%
2. VPhase measured the temperature at the top of the VX1 under steady-state conditions at 1kW load
3. Mean-Time Between Failures (MTBF) increases by around 30% for every 10K rise in temperature

EA Technology have undertaken analysis based on a real load profile obtained from the trial which provides, in our view, a more likely estimation of the lifespan of the VX1.

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<sup>12</sup> <http://www.relex.com/>

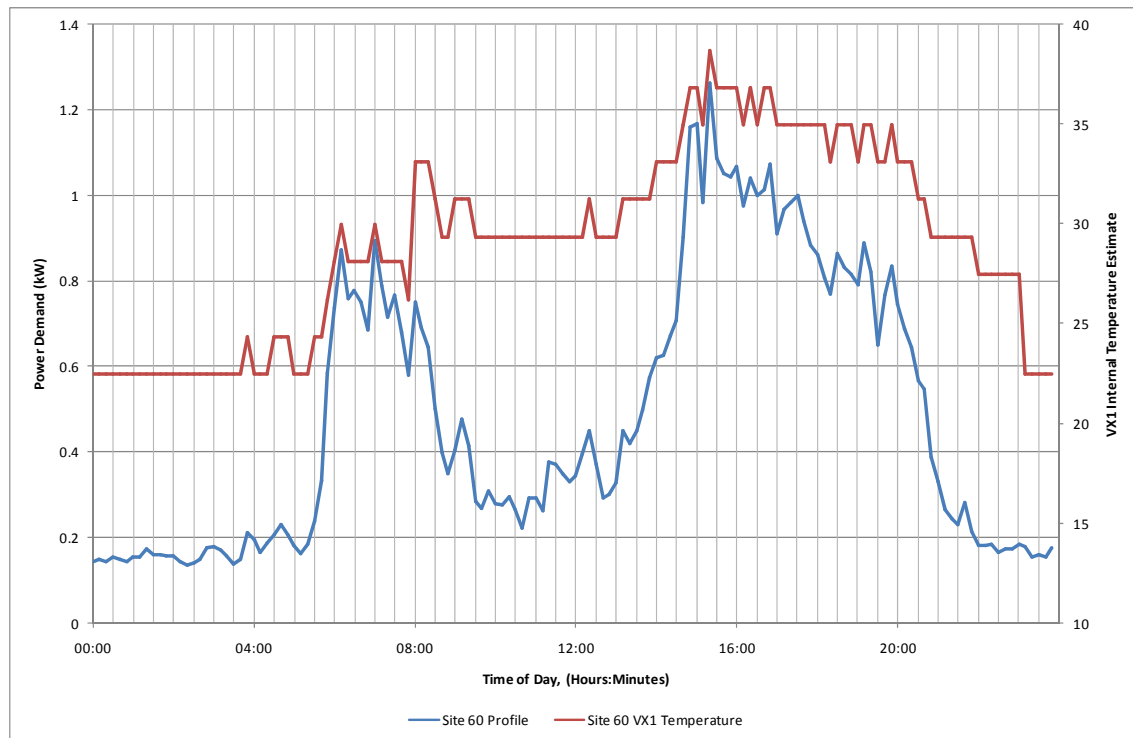
## 7.2 EA Technology Reliability Estimate

We note that the Relex reliability report employed confidence levels of 60%. We assume this to be the accepted standard for this type of equipment. If higher confidence levels were used then the expected lifetime would reduce, as the prediction becomes more conservative.

For the VPhase lifetime prediction, VPhase measured steady-state temperatures at several locations within the device enclosure, at a constant load of 1kW. The temperature measured at the top of the enclosure, which was the highest, was used in their prediction of a 26.6 year lifetime. This was produced with reference to the lifetime against temperature characteristic published in the Relex report. This is appropriate only if the average load on the device was expected to be about 1kW in its intended GB application.

Using data from the trial, we can provide a more accurate estimation of the typical loading condition of the VX1 device. To provide data for this, we chose Site 60, where the energy consumption, at 4240kWh/year, was close to the 2008 UK average of 4478kWh/year.

The load profile for this site is presented in Figure 9 (blue trace). It is the power demand for Site 60 against time-of-day, averaged across all the days in the analysis window for that site. There are two peaks, but for the vast majority of time, the device operates at demands significantly below 1kW.



**Figure 9: Power Demand Profile for Site 60, 4240kWh/year**

Using this load profile as a typical load cycle for the VX1, we predict the average temperature for an average UK property, at the top of the enclosure to be 29°C, which corresponds to a lifetime of 36 years in the Relex report. The following methodology was used:

- 1) Determine the time-of-day load profile for Site 60 from trial measurements
- 2) Scale this up to UK average consumption levels by multiplication by the ratio of UK average yearly energy consumption to Site 60 consumption (4478/4240, labelled "Site 60 Profile" in Figure 8)
- 3) Make the assumptions that: the temperature difference between the inner enclosure and the external ambient is proportional to the magnitude of internal losses, that losses are a base-load of 7.9W (See Appendix 3) plus 1% of the throughput of the device<sup>13</sup> and that the thermal time constant of the device is not significant
- 4) Linearly extrapolate the VPhase measured temperature rise against the magnitude of losses, for loads between 0 and 2kW, basing against VPhase steady-state temperature measurements at 1kW
- 5) Calculate the enclosure temperature by summation of the temperature rises with an assumed ambient temperature of 20°C between the hours of 08:00 and 22:00 and 15°C otherwise<sup>14</sup>.
- 6) Lookup extrapolated temperatures with respect to the load profile and plot ("Site 60 VX1 Temperature" in Figure 9)
- 7) Calculate the mean internal temperature of the VX1 (result = 29°C) and look up against Relx predicted MTBF, interpolating linearly between data points

We believe that this lifetime estimate, at 36 years is more likely than VPhase's own estimate, for the reasons previously described. Our worksheet, which contains the extrapolation of VX1 internal temperatures with respect to load is included in Appendix 8.

### 7.3 Carbon Emission Factor for Carbon Savings

There are several sources of carbon emissions factors for electrical energy consumption which have been used in the UK during recent years.

The CERT scheme uses carbon saving figures for measures that were determined for the Energy Efficiency Commitment (EEC) scheme, which in turn used the BRE Domestic Energy Model (BREDEM) on which BRE's Standard Assessment Procedure (SAP) is based. We consider that it is most important that a consistent basis is maintained between CERT measures. Hence we have used the SAP carbon emissions factor, which is a fixed coefficient invariant with respect to time.

Were the VX1 not to be within the CERT scheme, we would consider the use of a different factor. We believe the SAP factor to be the correct one, considering this application. It is noteworthy that the use of any carbon-emissions factor which reduces with time (according to the planned decarbonisation of electricity), apparently reduces the benefit of demand reduction in future years. However, the cost of achieving carbon emissions reduction is likely to increase as the country moves closer to the decarbonisation of electricity.

The pertinent details relating to the SAP factor are presented in Table 11.

<sup>13</sup> The actual loss percentage has little effect on the process described, 1% having been used as it was reported in documents during previous discussions with Ofgem. The actual loss percentage has not been tested by EA Technology.

<sup>14</sup> 20°C set to match the Relx report, 15°C set subjectively, for an assumed lower night-time ambient

**Table 11: Carbon Emissions Factors**

| Source  | Date       | Value (kgCO <sub>2</sub> /kWh) | Notes  |
|---|------------|--------------------------------|--|
| Building Research Establishment SAP <sup>15</sup> | March 2009 | 0.591 (Use and Savings)        | Includes whole emissions from ore extraction to consumption plus the effects of emissions of other pollutants<br>For use during SAP 2009, which runs 2010-2013 |

## 7.4 Assessment of Lifetime Carbon Abatement

The lifetime carbon abatement attributable to a VX1 device is calculated according to the following equation:

Lifetime carbon saving (kgCO<sub>2</sub>) = trial mean energy saving (%) \* UK average consumption (kWh/year) \* duration of the energy saving (years) \* carbon emissions factor (kgCO<sub>2</sub>/kWh)

The sources of each parameter are listed in Table 12, together with the carbon abatement value, which is 5.0 tCO<sub>2</sub> per device in a massed rollout.

**Table 12: Lifetime Carbon Abatement Potential of VX1 Device**

| Parameter                                 | Units                  | Source   | Value         |
|---|------------------------|--|---------------|
| Trial Mean Energy Saving %                | % of kWh/year          | CERT Trial / EA Technology                           | 5.2%          |
| UK Average Domestic Consumption           | kWh/year               | DECC <sup>b</sup>                                    | 4478 kWh/year |
| Duration of the Energy Saving             | Years                  | Relex Reliability Report / EA Technology Calculation | 36 years      |
| Carbon Emissions Factor of Electricity    | kgCO <sub>2</sub> /kWh | BRE SAP 2009   | 0.591         |
| <b>Carbon Abatement (tCO<sub>2</sub>)</b> |                        |  | <b>5.0</b>    |

Several assumptions are implicit in this calculation:

- UK average domestic consumption is fixed at 2008 levels during the lifespan of the VX1 device
- The performance of the device is unchanged during the lifespan of the VX1 device
- The nature of domestic load is unchanged during the lifespan of the VX1 device

The effect of the carbon saving of the VX1 has also been calculated on a whole-house basis, allowing for UK average gas and electricity usage. This results in a 2.2% carbon saving on a whole house basis (see Appendix 9 for details of the calculation).

EA Technology understands that a carbon score of 2.5 tonnes over a twenty year lifetime will currently apply to this measure, as decided by Ofgem, who have taken into consideration lifestyle changes and the continuing development and emergence of domestic voltage optimisation technologies.

<sup>15</sup> BRE, SAP 2009, "Revised emissions factors for the national calculation methodologies", March 2009

## 8 Conclusions

The trial has been carried out according to the Methodology submitted to Ofgem. Data was gathered for all 50 sites, for the minimum period of 60 days. A small number of sites were removed from the analysis for reasons which have been presented.



- 8.1: A site selection process was carried out, which whilst it could not exactly match the target demographics, was appropriate for a balanced assessment of the performance of the VX1.
- 8.2: Mean utility voltage and mean energy consumption for the trial as a whole closely matched UK average values.
- 8.3: The VX1 voltage optimisation device regulated voltage tightly to 220V. Exceptions were the “bypass” operation mode that allows the device to ride-out periods of high-power requirements and planned use of the bypass mode for the purpose of this trial.
- 8.4: At a small number of sites, problems with a timer device used to command the VX1 to change from the ON state to the OFF state (and vice-versa) meant that there were fewer state-changes than expected contained in the data acquired. However, over all 50 sites, due to staggered installations, some 2000 extra days of data were collected than allowed for in the Methodology.
- 8.5: A wide spread of energy savings was obtained, which meant that correlations of the carbon saving performance of the VX1 with respect to voltage and energy consumption, could not be determined with a high degree of confidence.
- 8.6: Four analysis algorithms were developed, each of which treats the data acquired in slightly different ways. All were tested for robustness and all four generally gave similar results for trial sites, from which we conclude that the performance of the device has been correctly determined.
- 8.7: Calculated savings varied from -4% to +19%. However, results from individual sites should not be considered in isolation without reference to confidence limits. For a few sites, energy saving results were negative.
- 8.8: The mean saving in electrical energy consumption, attributable to the VX1 devices, was determined from the trial as 5.2%, with a confidence limit on the mean of  $\pm 1.4\%$ .
- 8.9: The lifetime of a typical VX1 device was predicted to be 36 years, based upon independently-assessed estimates of reliability, measurements made by the manufacturer and data acquired during the trial itself.


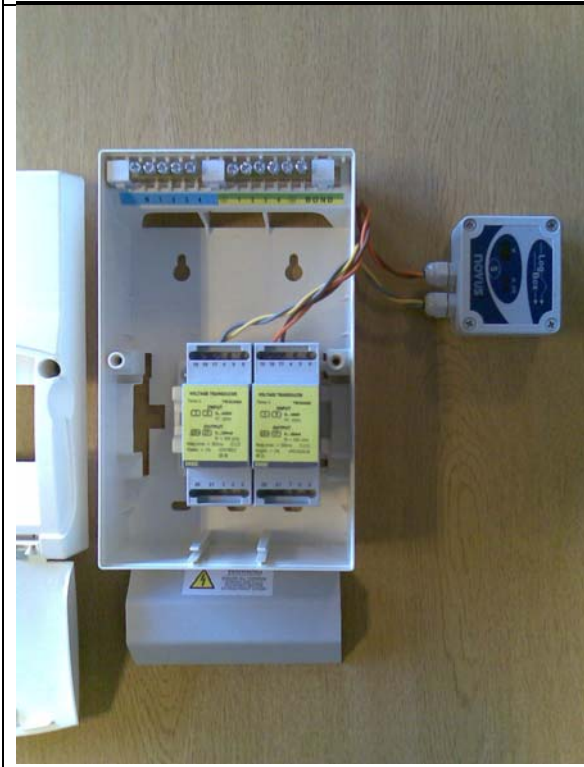


## Appendix 1 Monitoring Equipment

The monitoring equipment was chosen to be suitable for installations where the electricity meter was close to or removed from the distribution board. The monitoring equipment had the capability to record up to three months of household energy consumption data, utility voltage supply and VX1 output voltage.

The kit was designed to be unobtrusive and to have no displays. Data was downloaded using an infra-red connection link.

|   |  |
|---|--|
|   | <p><b>Monitoring Kit Contents</b><br/>4-way consumer unit containing:</p> <ul style="list-style-type: none"><li>Pulse logger</li><li>Voltage logger</li><li>Connection diagram</li><li>Voltage transducers</li><li>Serial number</li></ul> |
|  | <p><b>4-way consumer unit containing voltage logging equipment.</b></p>  |

|  |  |
|--|--|
|   | <p><b>Pulse logger 'Logbox DA' supplied with cable.</b><br/>Cable connects to the electricity meter PULSE OUTPUT.</p> <p>Blue to Pulse GND<br/>Brown to Pulse OPEN COLLECTOR</p>   |
|  | <p><b>Contents of the consumer unit.</b><br/>The unit contains a pre-wired 'Logbox AA' voltage logger, connected to two 0-400V transducers.</p> <p>Remove the protective cover to expose the voltage terminals. The transducers require wiring to two outputs from the property's consumer unit.</p> <p>LEFT transducer to 240V supply.<br/>RIGHT transducer to Vphase output.</p> |

## Appendix 2 Algorithm Test Results

A series of tests was performed using a pseudo-measurement set, to investigate the accuracy of the various algorithms and their response to certain features of site datasets.

**Table 13: Algorithm Test Results**

| Test | Description  | Algorithm 4   | Algorithm 3  | Algorithm 2  | Algorithm 1   |
|------|--|---|--|--|---|
| 1    | Bias Test ('perfect' input dataset-standard deviation and standby load set to zero)  | 5.0% ±0.1%  | 5.3% ±0.0%   | 5.0%   | 5.3%  |
| 2    | Bias Test (standby load set to zero, four different datasets generated with different random number seeds)   | 4.1% ±20%<br>12.8%±16%<br>-4.5% ±21%<br>8.5% ±20%<br><i>Average</i><br>5.2% | 4.1% ±0.0% <sup>16</sup><br>14.6%±0.0%<br>-4.4 %±0.0%<br>9.1% ±0.0%<br><i>Average</i> 5.9% | 4.0%<br>12.7%<br>-4.6%<br>8.3%<br><i>Average</i><br>5.1% | 4.9%<br>18.7%<br>7.6%<br>11.1%<br><i>Average</i><br>10.6% |
| 3    | Load Change Tests 0%,5%,10% (a percentage change in daily energy consumption was applied equally across the monitoring period, standard deviation set to zero) | 4.4% ±0.1%<br>4.5% ±0.1%<br>4.9% ±0.2%                                      | 4.6% ±0.0%<br>4.7% ±0.0%<br>5.2% ±0.0%   | 4.4%<br>4.6%<br>5.2%                                     | 4.6%<br>4.8%<br>5.5%                                      |
| 4    | Holiday (7-day holiday in middle of dataset, standard deviation set to zero) <sup>17</sup>   | 4.3% ±0.1%  | 4.5% ±5.0%   | 3.6%   | 4.5%  |

<sup>16</sup> Algorithm 3 confidence limits are zero due to the energy consumption per ON-day and per OFF-day being constant, which is according to the way that the test dataset was generated

<sup>17</sup> Energy demand was subjectively set, to 1kWh/day, during the holiday period

## Appendix 3 Measurement of VX1 Standby Load

Measurements of the standby load of the VX1 were made at EA Technology using a variac and a HAMEG HM8115-2 Programmable Power Meter, Serial 043440067

| State | ON/Active |
|-------|-----------|
| Note  | No-load   |

| State | OFF/Inactive |
|-------|--------------|
| Note  | No-load      |

| Voltage | Watts | Vars | Amps |
|---------|-------|------|------|
| 220     | 2.3   | 40   | 0.18 |
| 225     | 6.0   | 43   | 0.19 |
| 230     | 7.3   | 46   | 0.20 |
| 235     | 8.1   | 50   | 0.22 |
| 240     | 8.2   | 53   | 0.22 |
| 245     | 7.4   | 61   | 0.25 |
| 250     | 7.2   | 64   | 0.26 |
| 255     | 7.5   | 66   | 0.26 |
| 260     | 7.9   | 68   | 0.26 |

| Voltage | Watts | Vars | Amps |
|---------|-------|------|------|
| 220     | 2.5   | 40   | 0.18 |
| 225     | 2.5   | 42   | 0.19 |
| 230     | 2.5   | 44   | 0.19 |
| 235     | 2.6   | 45   | 0.19 |
| 240     | 2.7   | 47   | 0.20 |
| 245     | 3.0   | 49   | 0.20 |
| 250     | 3.2   | 51   | 0.20 |
| 255     | 3.3   | 52   | 0.20 |
| 260     | 3.5   | 54   | 0.21 |

|                          | ON/Active | OFF/Inactive |      |
|--------------------------|-----------|--------------|------|
| Average Load (235V-245V) | 7.9       | 2.8          | (W)  |
| Energy per Day           | 189.6     | 66.4         | (Wh) |

## Appendix 4 Individual Site Results

Results for individual sites should not be considered in isolation without reference to confidence limits. For a few sites, energy saving results are negative. This must not be taken as an indication that the VX1 device did not save energy at that site. Energy saving results contain a measurement of the energy saving plus an error, the effect of changing consumption patterns, which can be larger than the energy saving result. For example, Site 26 yielded a -0.4% energy saving to confidence limits of  $\pm 1.4\%$ . This means that the electrical energy saving was between minus 1.8% and plus 1%, to a confidence level of 95%.

### Notes:

Site Reference: Corresponds to the location of the site. The site reference ranges from 1-97. There are more than 50 because we originally expected to analyse 60 days from each site, and put any more than 60 days into a second file. Later, all data was moved to a single file.

Confidence Limit (CL): Calculated to a confidence level of 95%. CLs are calculated for Algorithm 4 and Algorithm 3.

Mean Utility Voltage: The average distribution network supply voltage over the analysis window.

Periods with a Bypass Event: The percentage of 10-minute periods in which a bypass event was detected (this is a detail of the device operation and is included for the interested reader)

Days in Calculation: The number of days in the analysis window. The window is shorter than the monitoring period by a least the start and end day of monitoring. Where the analysis window has been adjusted a note has been added.

Daily kWh: The average energy demand per day over the monitoring period.

Yearly kWh: The estimated consumption of the property if the daily energy demand was sustained over a whole year.

Note: Contains notes on the analysis window used, whether sites are abnormal or atypical, the toggling pattern of the site and any other pertinent details.

Site results are listed over page. Where results are highlighted in light-purple, fallback algorithms have been applied. Where results are highlighted in light-orange, they have been discarded from analysis. Reasons are evident in the 'Notes' column.

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note   |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|--|
| 1         | 3.8%                   | 4.4%                | 3.1%                   | 6.2%                | 2.9%                   | 2.9%                   | 240                      | 0%                          | 65                  | 9         | 3389       | Window 14/11/2009 to 18/01/2010<br>Toggling daily<br>Load constant with time   |
| 2         | 7.4%                   | 3.3%                | 6.4%                   | 6.0%                | 5.8%                   | 6.5%                   | 245                      | 0%                          | 89                  | 5         | 1729       | Window 19/01/2010 to 18/04/2010<br>Toggling daily<br>Load constant   |
| 3         | 13.3%                  | 4.4%                | 13.7%                  | 7.4%                | 11.4%                  | 13.6%                  | 246                      | 0%                          | 88                  | 6         | 2132       | Window 20/01/2010 to 18/04/2010<br>Toggling daily<br>Load reducing over time   |
| 4         | 18.8%                  | 4.2%                | 22.1%                  | 7.2%                | 18.0%                  | 22.0%                  | 252                      | 1%                          | 64                  | 8         | 3013       | Window 14/11/2009 to 17/01/2010<br>Toggling daily<br>Load constant<br>Very high voltage house  |
| 5         | 7.2%                   | 2.5%                | 6.3%                   | 6.9%                | 5.9%                   | 7.0%                   | 245                      | 1%                          | 112                 | 14        | 4978       | Window 15/12/2009 to 06/04/2010<br>Toggling daily<br>Load reducing slightly<br>A holiday period, an evaluation was made of the effect of removing it, there was not a significant effect   |
| 6         | 1.3%                   | 2.5%                | 1.1%                   | 5.6%                | 7.9%                   | 7.4%                   | 245                      | 9%                          | 119                 | 20        | 7456       | Window 01/12/2009 to 30/01/2010<br>Electric heating started after 30th (high base load for from 30/01/2010 to 04/03/2010)<br>Toggling daily<br>Algorithm3 and Algorithm 4 are unreliable at this site due to a few days of missing data, use Algorithm 2 instead |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note   |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|--|
| 7         | 16.5%                  | 3.5%                | 17.6%                  | 11.8%               | 14.0%                  | 19.4%                  | 245                      | 6%                          | 59                  | 14        | 5266       | Window 03/12/2009 to 30/01/2010<br>Toggling daily<br>Electric heating seems to be in use from 30/01/2010 (high base load). Excluded the period from 30th onwards   |
| 8         | 2.8%                   | 1.8%                | 3.0%                   | 7.3%                | 3.7%                   | 3.5%                   | 249                      | 3%                          | 105                 | 16        | 5947       | Window 23/12/2009 to 07/04/2010<br>Toggling daily<br>Load reducing over time<br>Moved end date to eliminate a holiday period   |
| 9         | 6.5%                   | 2.9%                | 6.8%                   | 7.7%                | 6.9%                   | 7.4%                   | 248                      | 2%                          | 118                 | 13        | 4599       | Window 20/01/2010 to 11/04/2010<br>Toggling daily<br>Load reducing over time   |
| 10        | 5.8%                   | 2.6%                | 6.1%                   | 7.0%                | 5.8%                   | 5.5%                   | 245                      | 4%                          | 52                  | 22        | 8175       | Window 26/05/2010 to 27/07/2010<br>Toggling daily<br>Voltage traces were transposed, have been corrected<br>Bad connection on VX1 voltage measurement during later period, does not seem to have affected the algorithms |
| 12        | 9.2%                   | 2.9%                | 10.0%                  | 6.8%                | 8.3%                   | 9.0%                   | 236                      | 4%                          | 54                  | 25        | 8946       | Window 20/01/2010 to 14/03/2010<br>Toggling daily<br>Moved end date as base load changed on the 15th   |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note  |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|---|
| 13        | 0.4%                   | 3.1%                | 0.4%                   | 7.3%                | 0.4%                   | 0.3%                   | 248                      | 3%                          | 96                  | 16        | 5790       | Window 20/01/2010 to 26/04/2010<br>Toggling daily<br>Load reducing over time<br>Central heating boiler not connected to VX1 - VPhase report significant source of savings at this time of year, hence site to be excluded |
| 14        | 1.8%                   | 3.4%                | 1.8%                   | 4.4%                | 2.1%                   | 1.8%                   | 243                      | 1%                          | 134                 | 8         | 2924       | Window 06/01/2010 to 20/05/2010<br>Toggling every 2 to 3 days<br>Load reducing over time  |
| 15        | 5.0%                   | 2.8%                | 5.2%                   | 4.5%                | 5.0%                   | 5.1%                   | 237                      | 1%                          | 126                 | 10        | 3753       | Window 20/01/2010 to 26/04/2010<br>Toggling daily<br>Load reducing over time  |
| 16        | 5.0%                   | 2.2%                | 5.3%                   | 4.9%                | 4.9%                   | 6.8%                   | 235                      | 1%                          | 124                 | 14        | 5270       | Window 19/11/2009 to 07/01/2010<br>Toggling 2 to 3 days<br>Load increasing<br>Excluded a holiday period   |
| 17        | 5.6%                   | 3.3%                | 5.5%                   | 9.4%                | 4.6%                   | 5.0%                   | 246                      | 1%                          | 85                  | 9         | 3209       | Windows 29/01/2010 to 21/05/2010<br>Toggling 2 to 3 days<br>Load increasing<br>Five periods of no occupancy hence underestimate of savings  |
| 19        | 7.2%                   | 3.2%                | 7.6%                   | 9.5%                | 8.1%                   | 8.1%                   | 246                      | 1%                          | 122                 | 11        | 4174       | Window 21/01/2010 to 23/05/2010<br>Toggling 2 to 3 days   |
| 20        | 11.4%                  | 8.2%                | 12.8%                  | 9.3%                | 11.7%                  | 12.5%                  | 251                      | 0%                          | 55                  | 4         | 1323       | Window 27/05/2010 to 21/07/2010<br>Reconstructed on/off days when the voltage trace was lost  |



| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note   |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|--|
| 21        | 2.5%                   | 9.3%                | 2.6%                   | 6.8%                | 5.9%                   | 4.8%                   | 247                      | 0%                          | 117                 | 6         | 2172       | Window 21/01/2010 to 18/04/2010<br>Toggling every 2 to 3 days<br>Toggling is irregular, use Algorithm 2<br>Load reducing over time   |
| 22        | 0.2%                   | 2.6%                | 0.6%                   | 3.6%                | 0.3%                   | 1.1%                   | 247                      | 1%                          | 99                  | 5         | 1683       | Window 24/02/2010 to 07/05/2010<br>Toggling daily after the 24th<br>Load reducing  |
| 23        | 0.7%                   | 2.7%                | 0.8%                   | 5.1%                | -0.2%                  | -0.1%                  | 236                      | 5%                          | 83                  | 15        | 5586       | Window 28/04/2010 to 28/05/2010<br>Toggling daily<br>Load reducing over time<br>Some data was missed due to an incorrectly fitted voltage logger and a VX1 failure   |
| 24        | 2.0%                   | 4.5%                | 2.2%                   | 3.4%                | 1.5%                   | 2.6%                   | 249                      | 1%                          | 35                  | 10        | 3785       | Window 16/03/2010 to 20/04/2010<br>Energy logger failed on 21/04/2010 so no useful data after 20/04/2010<br>Garage circuits were not connected to VX1, significant savings were expected on the freezer and garden pond pumps, which were in continuous running<br>Hence, excluded from the analysis |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note  |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|---|
| 26        | -0.4%                  | 1.4%                | 0.5%                   | 5.4%                | 0.2%                   | -1.6%                  | 245                      | 8%                          | 66                  | 23        | 8499       | Window 23/01/2010 to 03/05/2010<br>Moved start to start of toggles and end to before a holiday period<br>Toggling daily<br>Large property with two consumer units, VX connected to one only, loads unknown hence to be excluded |
| 27        | 3.7%                   | 3.6%                | 3.9%                   | 8.3%                | 3.0%                   | 5.6%                   | 248                      | 3%                          | 93                  | 9         | 3129       | Window 16/02/2010 to 20/05/2010<br>Toggling 2 -3 days<br>Load reducing  |
| 32        | 8.7%                   | 2.5%                | 9.5%                   | 3.2%                | 8.4%                   | 9.4%                   | 244                      | 2%                          | 82                  | 17        | 6216       | Window 24/02/2010 to 17/05/2010<br>Toggling daily<br>Load reducing over time  |
| 33        | 5.8%                   | 2.6%                | 5.2%                   | 8.3%                | 1.5%                   | 1.4%                   | 240                      | 1%                          | 166                 | 16        | 5961       | Window 01/12/2010 to 16/05/2010<br>Toggling 2 to 3 days<br>Load reducing over time  |
| 37        | -2.8%                  | 2.2%                | -2.3%                  | 3.0%                | -2.6%                  | -2.4%                  | 250                      | 1%                          | 186                 | 13        | 4890       | Window 12/11/2009 to 16/05/2010<br>Toggling daily<br>Load increasing  |
| 38        | 2.7%                   | 2.1%                | 3.3%                   | 4.8%                | 0.4%                   | 1.0%                   | 250                      | 2%                          | 149                 | 8         | 3076       | Window 18/12/2009 to 16/05/2010<br>Toggling 2 to 3 days   |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note   |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|--|
| 39        | -4.6%                  | 5.1%                | -4.4%                  | 9.3%                | -4.1%                  | -3.7%                  | 242                      | 2%                          | 83                  | 11        | 4146       | Window 22/02/2010 to 17/05/2010<br>Toggling daily<br>Load increasing<br>Garage circuits were not connected to the VX1, hence savings may be underestimates for this site   |
| 42        | 3.1%                   | 3.1%                | 2.5%                   | 9.5%                | 2.3%                   | 2.3%                   | 239                      | 2%                          | 55                  | 24        | 8854       | Window 26/05/2010 to 22/07/2010<br>Toggling daily<br>VX1 did not toggle prior to 26/05/2010  |
| 48        | 1.3%                   | 2.1%                | 1.2%                   | 3.9%                | 1.5%                   | 1.2%                   | 244                      | 2%                          | 174                 | 15        | 5457       | Window 01/12/2009 to 24/05/2010<br>Toggling 2 to 3 days at first then daily<br>Load increasing   |
| 50        | 3.1%                   | 1.7%                | 3.4%                   | 4.7%                | 2.6%                   | 3.7%                   | 246                      | 7%                          | 149                 | 27        | 9995       | Window 23/02/2010 to 21/07/2010<br>Toggling daily from the 23rd (not previously)<br>Load decreasing<br>Missing portion of voltage data from 19/04/2010 to 18/05/2010, regenerated with 245V supply voltage                         |
| 54        | 3.3%                   | 5.2%                | -0.7%                  | 7.7%                | -0.4%                  | -0.5%                  | 250                      | 2%                          | 71                  | 6         | 2291       | Window 16/03/2010 to 20/05/2010<br>Excluded a holiday period at the start of the data<br>Central heating boiler not connected to VX1, informed that this is source of high savings hence this site is to be excluded from analysis |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note   |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|--|
| 56        | 6.5%                   | 6.2%                | 6.7%                   | 6.4%                | 6.7%                   | 6.4%                   | 249                      | 1%                          | 55                  | 6         | 2046       | Window 14/03/2010 to 08/05/2010<br>Toggling daily from the 14th<br>Load decreasing   |
| 58        | 15.6%                  | 9.7%                | 7.5%                   | 30.5%               | 14.5%                  | 17.0%                  | 245                      | 3%                          | 19                  | 13        | 4644       | Window 28/04/2010 to 17/05/2010<br>Toggling daily<br>Load increasing<br>No toggling during the first two downloads<br>due to a timer failure                               |
| 60        | 5.1%                   | 3.2%                | 4.5%                   | 6.0%                | 3.2%                   | 4.4%                   | 248                      | 1%                          | 166                 | 12        | 4240       | Window 21/11/2009 to 06/05/2010<br>Toggling daily<br>Load increasing   |
| 64        | 0.4%                   | 2.4%                | 0.4%                   | 3.4%                | 0.5%                   | 0.3%                   | 238                      | 1%                          | 97                  | 7         | 2464       | Window 20/01/2010 to 27/04/2010<br>Toggling daily<br>Constant load   |
| 65        | 6.2%                   | 4.1%                | 6.5%                   | 5.4%                | 5.6%                   | 6.4%                   | 235                      | 1%                          | 147                 | 6         | 2144       | Window 02/12/2009 to 27/04/2010<br>Toggling daily<br>Load increasing<br>Kerswell has quite low utility voltage, often<br>down to 225V                                      |
| 67        | 4.2%                   | 3.6%                | 4.4%                   | 7.4%                | 2.3%                   | 2.8%                   | 247                      | 0%                          | 61                  | 16        | 5834       | Window 25/02/2010 to 28/04/2010<br>Reconstructed on/off days according to an<br>early voltage measurement, later voltage<br>measurements were not recorded<br>successfully |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note  |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|---|
| 68        | -1.3%                  | 3.0%                | -1.5%                  | 4.7%                | 0.0%                   | -1.4%                  | 243                      | 2%                          | 116                 | 15        | 5498       | Window 22/01/2010 to 17/05/2010<br>Toggling daily<br>Load decreasing  |
| 70        | 4.6%                   | 3.3%                | 2.0%                   | 9.4%                | 4.8%                   | 7.9%                   | 239                      | 2%                          | 185                 | 10        | 3473       | Window 20/11/2009 to 24/05/2010<br>Toggling 2 to 3 days<br>Load increasing<br>Holidays in evidence  |
| 72        | 6.6%                   | 3.1%                | 7.0%                   | 6.3%                | -2.7%                  | -1.6%                  | 241                      | 16%                         | 58                  | 33        | 12180      | Window 24/02/2010 to 23/04/2010<br>Toggling daily<br>Load reducing over time<br>VPhase note that dining-room sockets, an unknown 16A circuit and shower pump were not connected to the VX1<br>We have left this property in the analysis since these probably account for a small proportion of the load/savings expected from the device |
| 73        | 5.4%                   | 3.5%                | 5.8%                   | 11.5%               | 5.4%                   | 5.9%                   | 250                      | 2%                          | 71                  | 9         | 3411       | Window 17/03/2010 to 27/05/2010<br>Toggling daily after 17/03/2010 so used that as the start date<br>Load reducing over time<br>Quite irregular consumption pattern   |
| 79        | 2.1%                   | 2.6%                | 1.1%                   | 2.9%                | 0.4%                   | 2.0%                   | 240                      | 1%                          | 158                 | 4         | 1504       | Window 19/11/2009 to 26/04/2010<br>Toggling daily<br>Load constant  |

| Site Ref. | Algorithm 4 Result (%) | CL Algorithm 4 (±%) | Algorithm 3 Result (%) | CL Algorithm 3 (±%) | Algorithm 2 Result (%) | Algorithm 1 Result (%) | Mean Utility Voltage (V) | Periods with a Bypass Event | Days in Calculation | Daily kWh | Yearly kWh | Note  |
|-----------|------------------------|---------------------|------------------------|---------------------|------------------------|------------------------|--------------------------|-----------------------------|---------------------|-----------|------------|---|
| 80        | 3.8%                   | 4.4%                | 6.5%                   | 10.2%               | 5.7%                   | 5.5%                   | 244                      | 1%                          | 105                 | 6         | 2095       | Window 01/02/2010 to 17/05/2010<br>Toggling 2 to 3 days   |
| 83        | 4.6%                   | 2.4%                | 4.8%                   | 5.5%                | 5.6%                   | 5.6%                   | 251                      | 2%                          | 77                  | 9         | 3284       | Window 02/03/2010 to 18/04/2010<br>Toggling 2 to 3 days<br>Load reducing<br>Some holidays in evidence in the later period |
| 90        | 1.1%                   | 2.4%                | 1.1%                   | 4.0%                | 1.8%                   | 2.0%                   | 246                      | 1%                          | 135                 | 11        | 3935       | Window 21/01/2010 to 26/04/2010<br>Toggling daily<br>Load reducing  |
| 93        | 6.7%                   | 2.5%                | 6.8%                   | 8.1%                | 7.6%                   | 8.1%                   | 253                      | 4%                          | 177                 | 11        | 4039       | Window 27/11/2009 to 23/05/2010<br>Toggling 2 to 3 days<br>Load reducing  |
| 95        | -3.9%                  | 2.7%                | -3.4%                  | 5.4%                | -4.2%                  | -3.8%                  | 245                      | 1%                          | 131                 | 14        | 5039       | Window 14/01/2010 to 11/04/2010   |
| 97        | -1.6%                  | 2.3%                | -1.6%                  | 6.0%                | -1.3%                  | -1.1%                  | 246                      | 4%                          | 116                 | 16        | 5940       | Window 20/01/2010 to 16/05/2010<br>Toggling daily<br>Load decreasing  |

## Appendix 5 Distributions of Energy, Voltage and Energy Saving

### Section 1: Distributions of energy consumption, mean voltage and energy saving in the trial

The following histograms show the distributions of yearly energy consumption and mean utility supply voltage recorded at the trial sites. The bars are aligned with x-axis values which correspond to the upper limit of each bar.

For example in Figure 10, the first bar is at 2000kWh. Hence there were 4 sites at which the yearly energy consumption was between 1001 and 2000kWh.

In Figure 12, the Normal Distribution (with mean and standard deviation as per Section 6.5) is plotted for comparison with the distribution of energy saving percentages determined from trial sites.

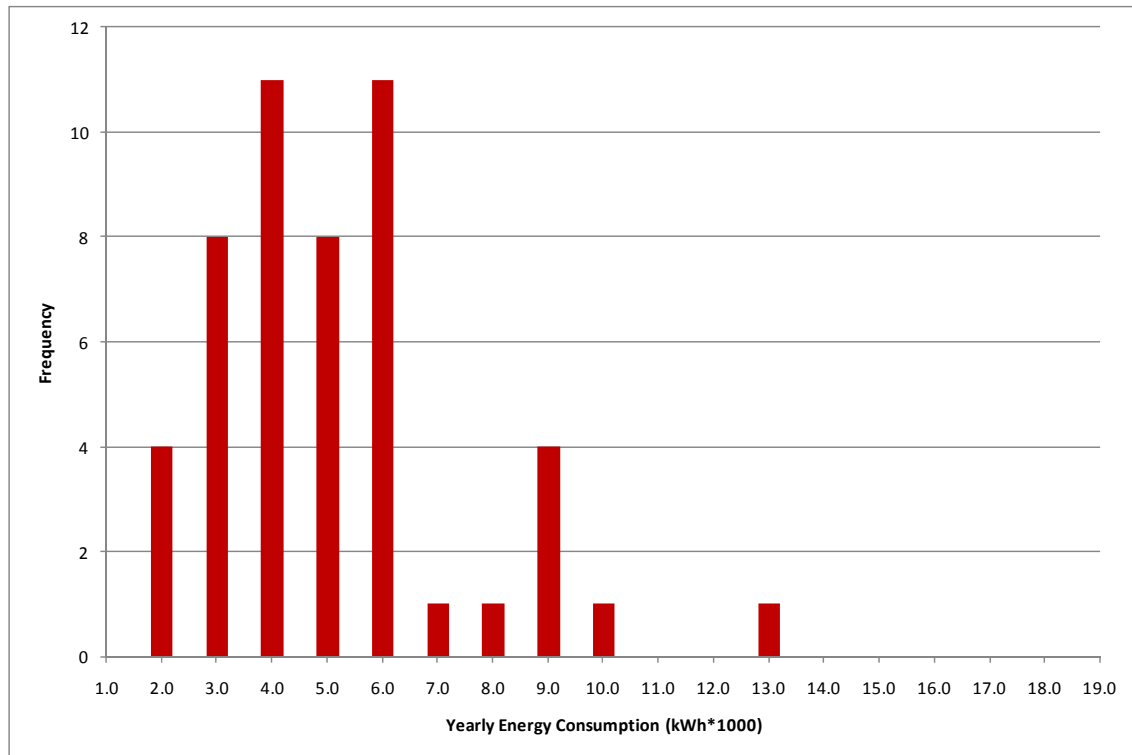


Figure 10: Distribution of Estimated Yearly Energy Consumption for Trial Sites

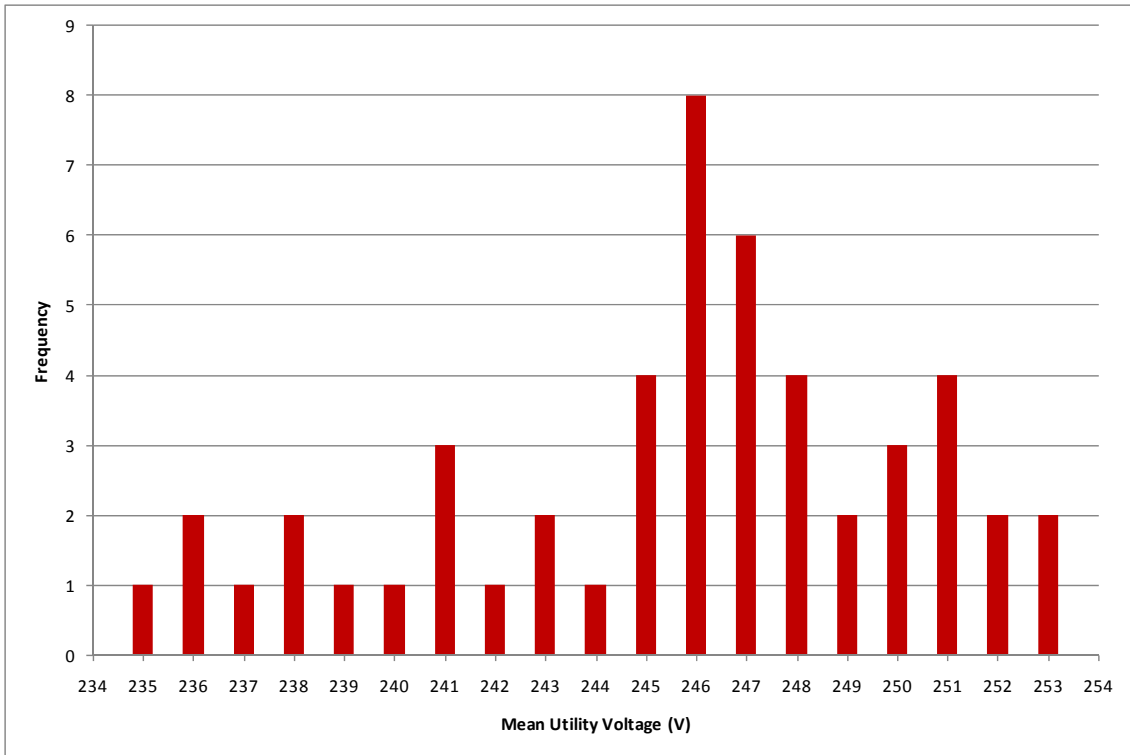


Figure 11: Distribution of Mean Utility Voltage for Trial Sites

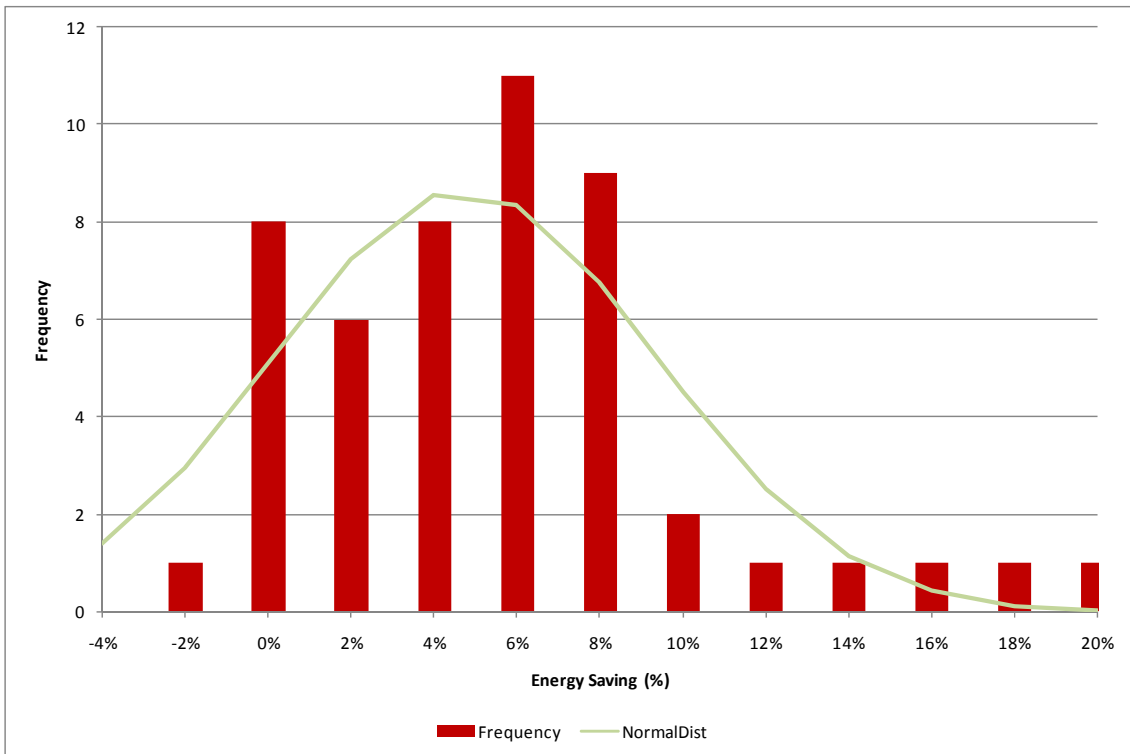


Figure 12: Distribution of Energy Saving Percentages for Trial Sites



### Section 2 – Correlations of percentage energy saving with voltage and consumption

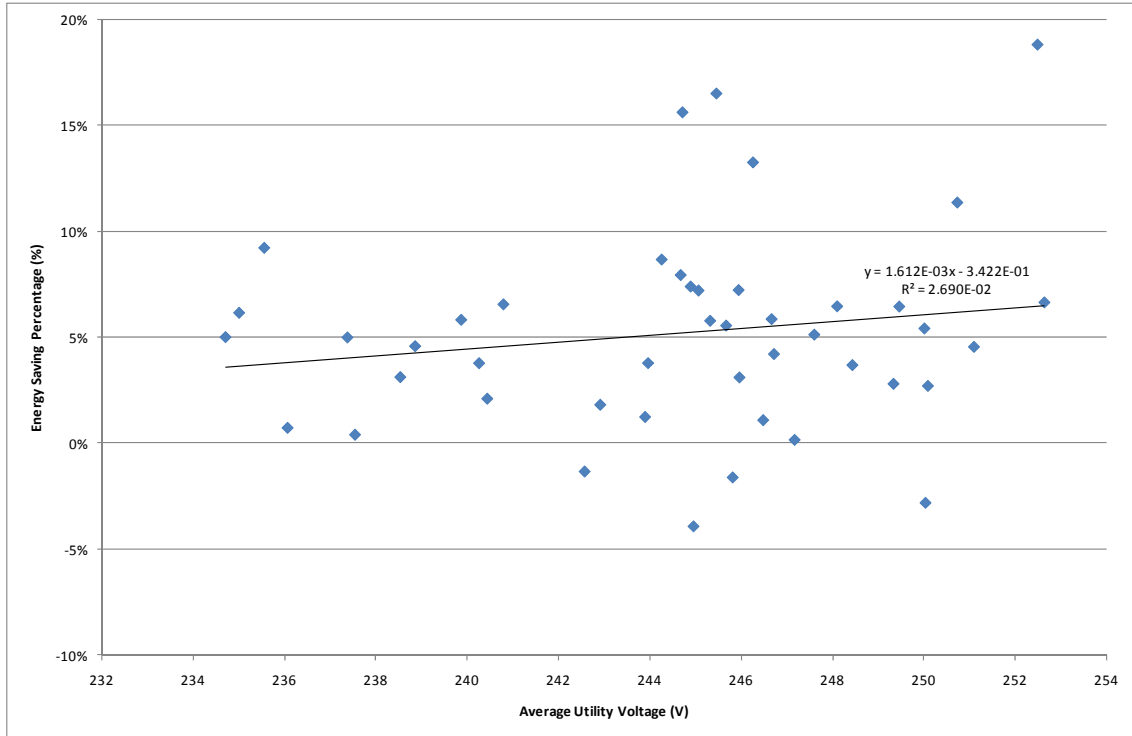


Figure 13: Correlation of Percentage Energy Saving with Mean Utility Voltage

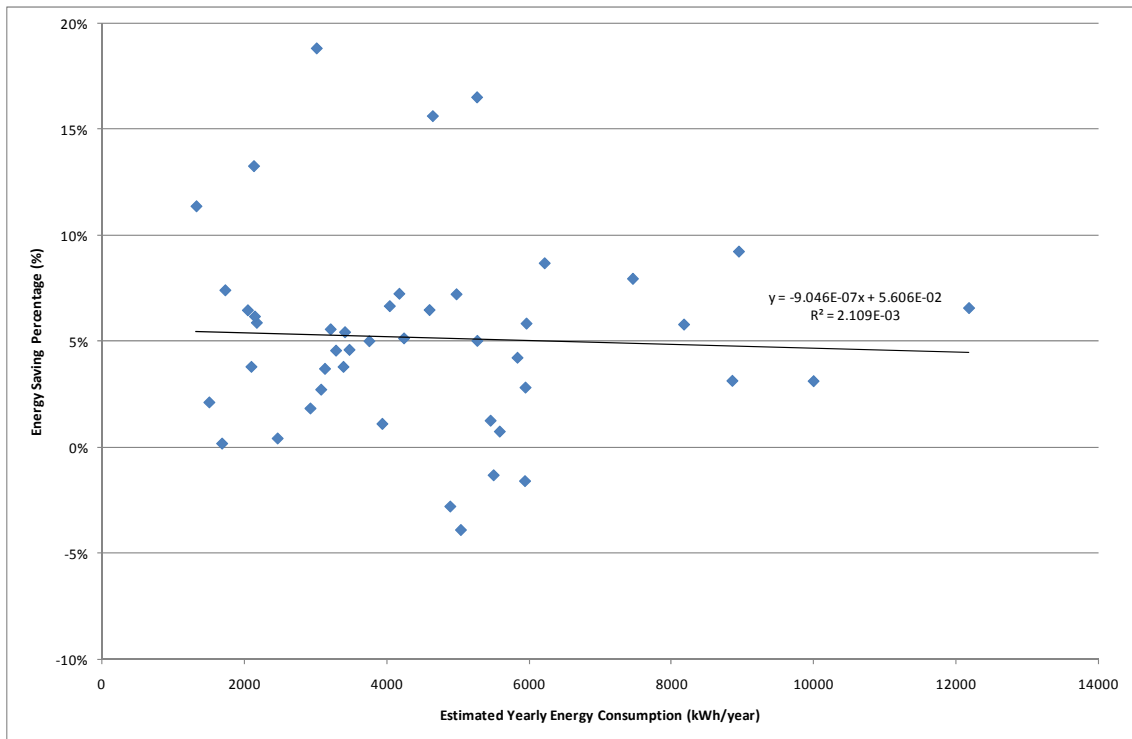
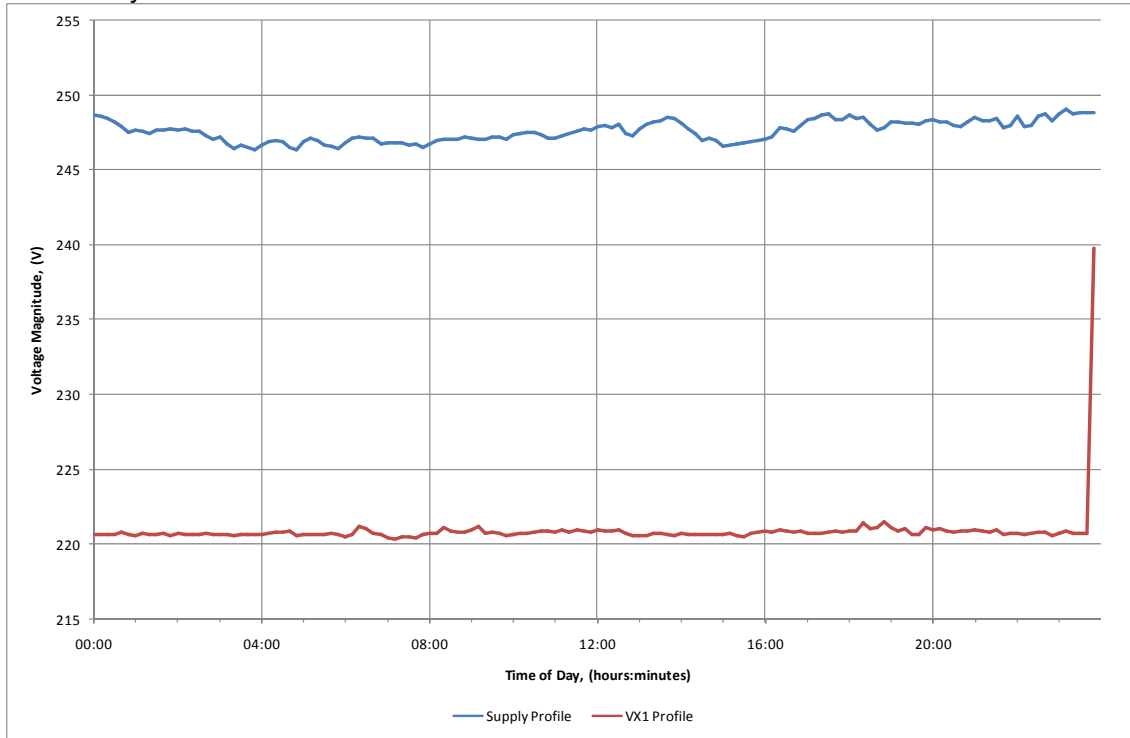


Figure 14: Correlation of Energy Saving Percentage with Estimated Yearly Energy Consumption

### Section 3: Energy demand and supply voltage variations at three sites

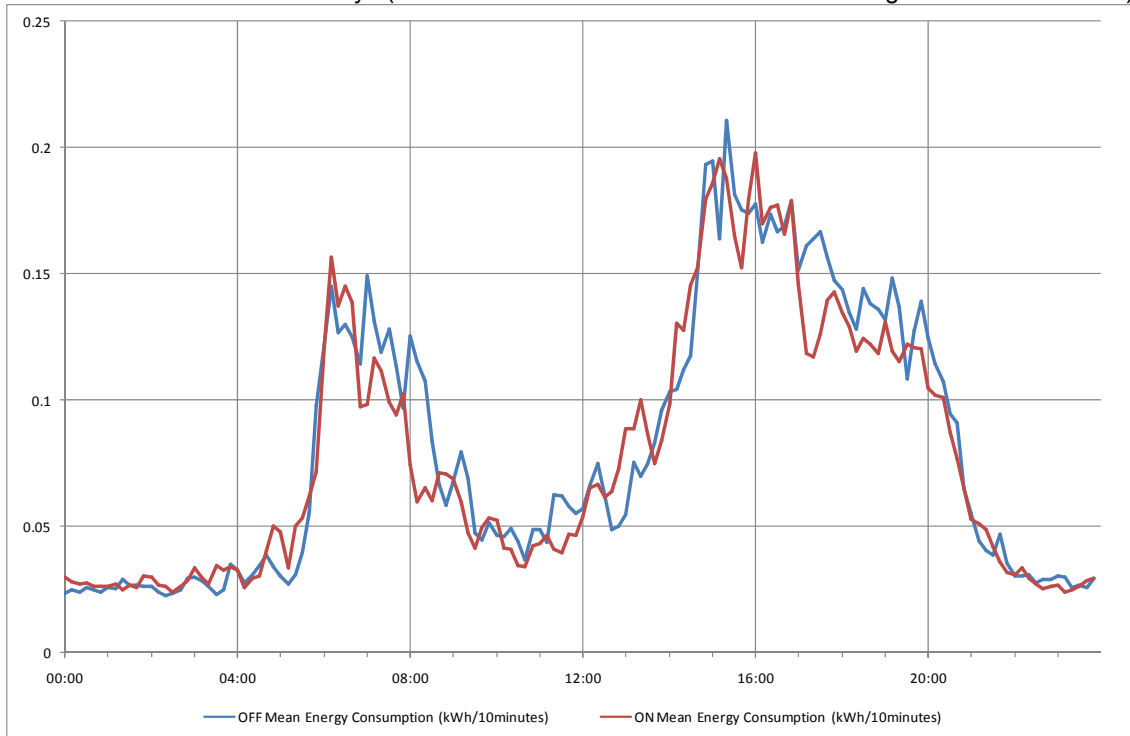
Site 60: Energy saving 5.1%  $\pm$ 3.2%, mean supply voltage 248V, consumption 4240kWh/year



**Figure 15: Site 60 Daily Voltage Profiles**

“Supply Profile” – mean for ON and OFF days

“VX1 Profile” – mean for ON days (can show effects at the ends due to switching ON/OFF of the VX1)



**Figure 16: Site 60 Daily ON and OFF Demand Profiles**

Site 65: Energy saving 6.2%  $\pm$ 5.4%, mean supply voltage 235V, consumption 2144kWh/year

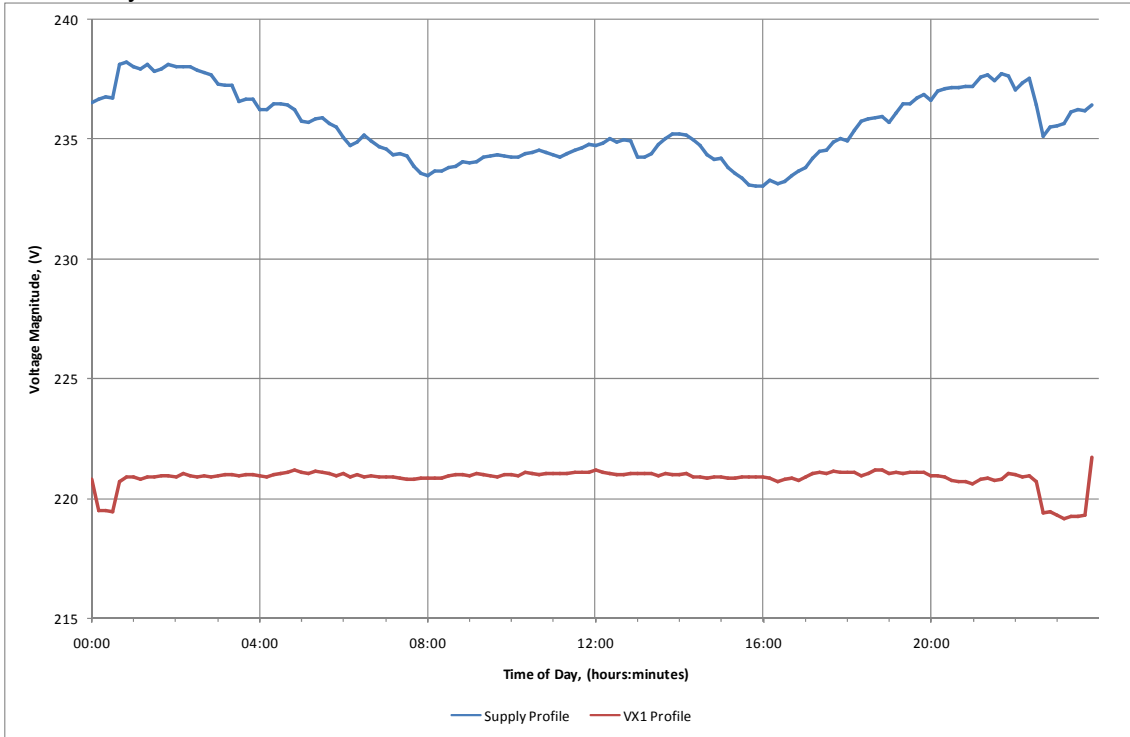


Figure 17: Site 65 Daily Voltage Profiles

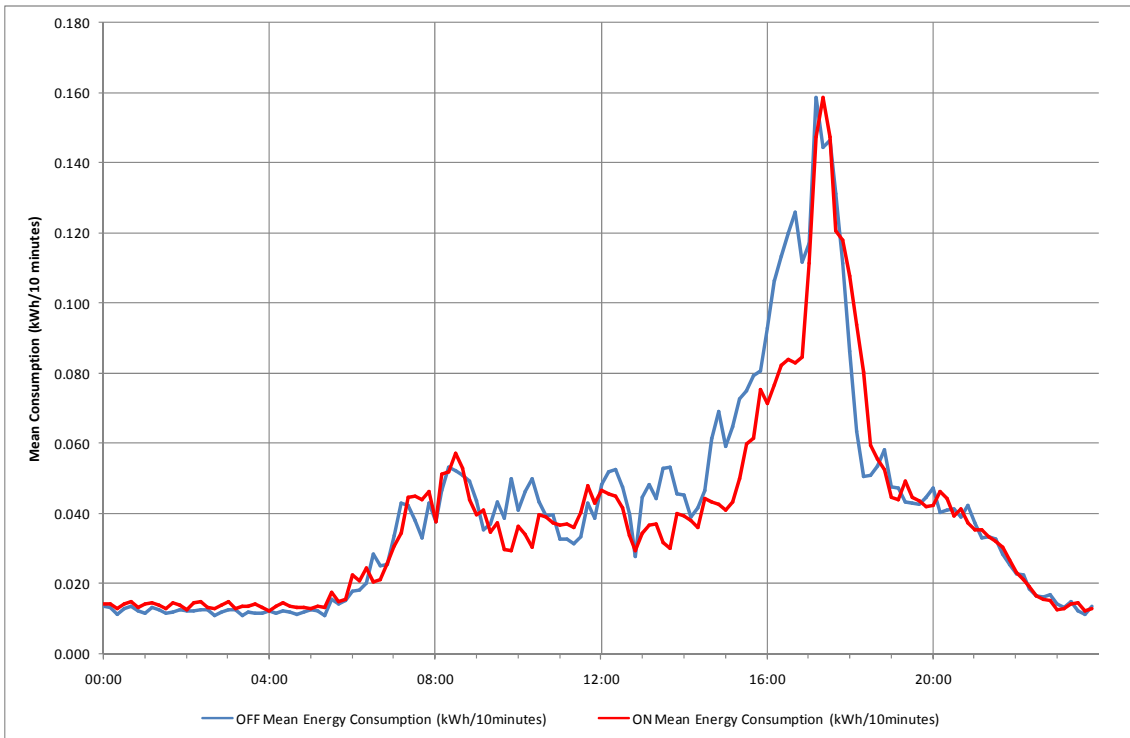


Figure 18: Site 65 Daily ON and OFF Demand Profiles

Site 37: Energy saving  $-2.8\% \pm 2.2\%$ , mean supply voltage 250V, consumption 4890kWh/year

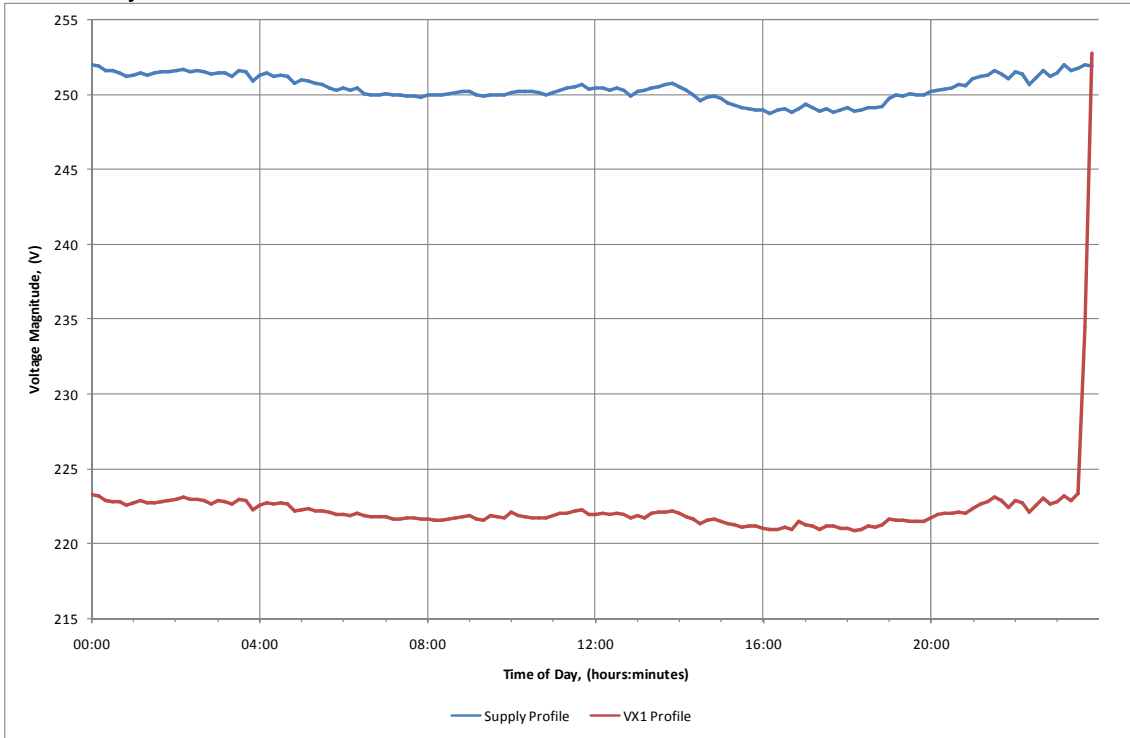


Figure 19: Site 37 Daily Voltage Profiles

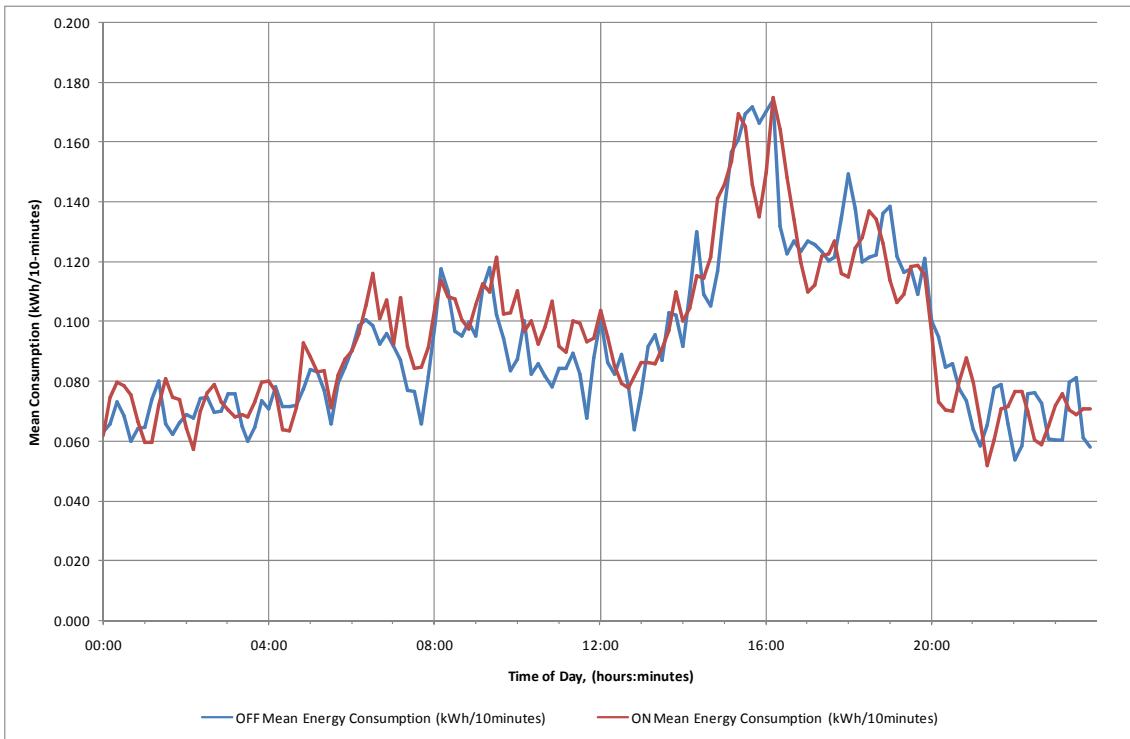


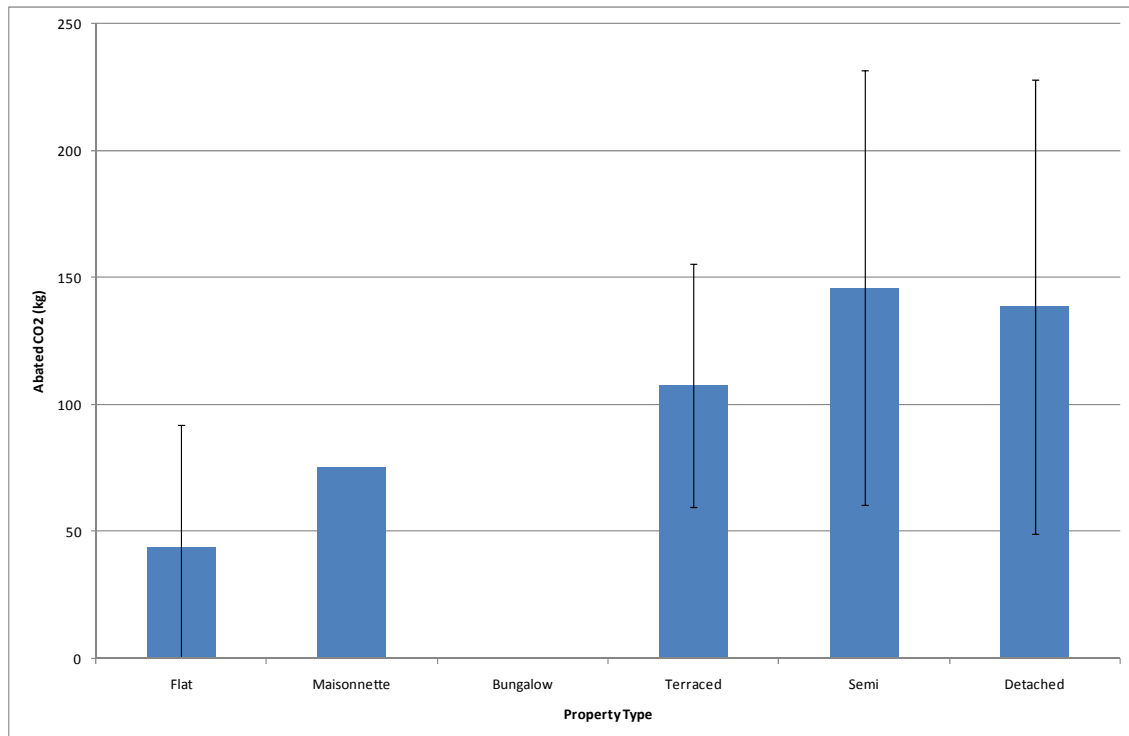
Figure 20: Site 37 Daily ON and OFF Demand Profiles

## Section 4 – Abated Carbon by Property Type

In this Section the carbon abatement value of the VX1 is broken down into different types of properties. Table 14 and Figure 1 present these breakdowns. While this abatement generally shows the carbon abatement value to increase with size of property, the sample size is too small for these values to be confidently determined.

**Table 14: CO<sub>2</sub> Abatement by Property type**

|             | Mean<br>kgCO <sub>2</sub> /year | Confidence<br>±kgCO <sub>2</sub> /year |
|-------------|---------------------------------|--|
| Flat        | 44                              | 49                                     |
| Maisonnette | 75                              | -                                      |
| Bungalow    | -                               | -                                      |
| Terraced    | 108                             | 48                                     |
| Semi        | 146                             | 86                                     |
| Detached    | 138                             | 89                                     |



**Figure 21: Abated Carbon by Property Type**

Note that for “Maisonnette”, only a single value was obtained, so no confidence limits have been determined. Also note that while there were two Bungalows in the trial, both results were discarded for reasons presented in Appendix 4. Hence there is no carbon abatement result.

# **Appendix 6      Relex Reliability Prediction Report**

## **Appendix 7 VPhase Discussion of Relex Reliability Report**

The following document is the VPhase interpretation of the Relex reliability report. It covers a small number of changes that were required to the device for Electromagnetic Compatibility Testing (EMC) compliance and assesses by measurement the likely temperature rise of the VX1 device in operation.

VPhase Report 087v1 is included overpage.

## Discussion of VPhase VX1 Independent reliability report

A reliability report was carried out on the VPhase VX1 unit by the Relex Software Corporation on the 13<sup>th</sup> April 2009. The report stated that the failure rate of the VX1 was calculated to be 2218.709835 FITs (failures per billion hours) which yielded a MTBF of 450,712 hours, or 51 years.

Since this initial report a small number of components have been changed to enable the unit to pass EMC testing, and a few components have been removed as they are no longer required.

The effect of the component changes and the results of the reliability report are discussed in this document.

### Components that have been removed

One of the methods of improving reliability is to reduce component count. When finalizing the BOM for the production unit a few components were found to be redundant and have been removed from the BOM, these are:

1. A 74HC74 dual d-type flip flop was used as a clock divider during development. The microcontroller clock frequency has now been fixed so the 74HC74 has now been removed from the BOM.
2. Two small drum core inductors were used to filter the power rails. These are now no longer required and have been removed from the BOM.

The details of the components that can be removed from the Relex report are:

| Reason for Removal | Part Number     | Ref Des | Mfr Part Number | Category           | Qty | Failure Rate (FITs) | MTBF (hours) |
|--------------------|-----------------|---------|-----------------|--------------------|-----|---------------------|--------------|
| 1.                 | ICT-74HC74/SM   | IC8     | SN74ACT74D      | Integrated Circuit | 1   | 27.432817           | 36452690.65  |
| 2.                 | IND-2M2H/PK0810 | L1      | PK0810-222      | Inductor           | 1   | 6.296809            | 158810593.99 |
| 2.                 | IND-2M2H/PK0810 | L2      | PK0810-222      | Inductor           | 1   | 6.296809            | 158810593.99 |

Removal of these components will not have adversely affected the MTBF calculation for the VPhase VX1, instead they will have slightly improved the result.

### Altered Components

During the EMC compliance testing a number of components had to be changed to ensure the unit would meet the EMC testing criteria.

1. The biggest alteration involved changing the FCB20N60F MOSFETs (12.5A 600V) to 5N120BND IGBTs (21A 1200V). The change wasn't made because of the power rating of the devices; instead the change was made due to the EMI caused by the integrated body diodes.



The higher power 5N120BND IGBTs had a much better EMI performance during EMC testing. The result of this change is that the FIT value for this component has now increased, i.e.

|               | Part Number   | Ref Des      | Mfr Part Number | Category      | Qty | Failure Rate (FITs)* | MTBF (hours) |
|---------------|---------------|--------------|-----------------|---------------|-----|----------------------|--------------|
| Old Component | TRS-FCB20N60F | T17..<br>T20 | FCB20N60F       | Semiconductor | 4   | 12.9                 | 99323675.77  |
| New Component | HGTG5N120BND  | T17..<br>T20 | 5N120BND        | Semiconductor | 4   | 20.3                 | Unknown      |

\*FIT values taken from manufacturers website ([www.fairchildsemi.com](http://www.fairchildsemi.com))

The FIT value has increased from 12.9 to 20.3 for this component so it would appear that it will have a slightly negative impact upon the Relx reliability calculation. Although, the new component has a much higher rating 21A 1200V as opposed to 12.5A 600V, so will be run at a much lower stress rating which in turn will greatly improve the reliability of the device.

- The transistors that were driving the optocouplers have been changed from Fairchild BC847 to Fairchild MOSFETs BSS138. This has resulted in an improved FIT value and should correspond to an improved reliability calculation. The component values can be seen here:

|               | Part Number | Ref Des  | Mfr Part Number | Category      | Qty | Failure Rate (FITs)* | MTBF (hours) |
|---------------|-------------|----------|-----------------|---------------|-----|----------------------|--------------|
| Old Component | TRS-BC847   | T1,3,4,5 | BC847           | Semiconductor | 4   | 4.2                  | 273618112.2  |
| New Component | BSS138      | T1,3,4,5 | BSS138          | Semiconductor | 4   | 2.7                  | Unknown      |

\*FIT values taken from manufacturers website ([www.fairchildsemi.com](http://www.fairchildsemi.com))

- A watchdog clock has been added to enable the CPLD to detect whether the primary control clock has failed. This circuit wasn't on the existing design, but it does use the Hex inverter (IC7 – SN74ACT74D) that was included on the original BOM. This additional feature should not affect the reliability report as the components have already been included in the calculation.
- To improve the conducted emission results the front end filtering of the device had to be altered. Two components were altered here, the 1uF capacitor (C43 - MKP1840-510/635-2M) was increased to 2.2uF (MKP1840-522/635-2M), and an inductor (L6 LC24-086) was added to the front end. The increase in rating of capacitor should have no effect as it is still from exactly the same family of capacitors and is made using the same manufacturing processes.

The input inductor L6 is a custom wound component so no reliability data is available for it. Taking into account that two inductors have already been removed from the BOM (see section 1) the addition of this extra inductor on the front end of the power convertor should have little effect upon the Relx cumulative reliability calculation.

### Change Summary

A number of small changes have been made to the bill of materials that was used by Relx Software Corporation to generate the original reliability/lifetime figures. None of these changes should

significantly alter the original reliability/lifetime figures as the FIT values have not been greatly altered, and where they have been changed slightly, they should be offset by the removal of other components (and their corresponding probability of failure values) when factored into the cumulative probability of failure calculation.

### **Lifetime Calculation**

In the Relux report the failure rate of the VX1 was predicted to be 2218.709835 FITs yielding a MTBF of 450,712 hours or 51 years. This calculation was performed using a 21°C ambient temperature. On pages 13 and 14 (Section 7) the FIT values and MTBF values have been plotted versus temperature. As the ambient temperature increases the Failures In Time (FITs) will increase and the Mean Time Between Failures (MTBF) will decrease. Both these values indicating that the lifetime of the unit will decrease as the temperature of the unit increases. Using the graph on page 14 (MTBF vs Temperature) it is possible to determine the predicted lifetime of the unit for a given temperature. For example, if the temperature inside the unit is 30°C then the corresponding MTBF is 304,528 hours, which is 34.7 Years.

To determine the likely lifetime of the VPhase VX1 in real operational temperatures a number of tests have been conducted in which the internal temperature of the enclosure and the ambient temperature have been recorded.

For the purposes of the tests the VX1 VPhase unit (serial no. 107110482) was connected to a 245V AC supply. With the unit regulating and the output voltage reduced to 220V AC a load of 1KW was connected. The internal temperature of the enclosure was monitored by placing thermocouples in three positions A, B and C inside the VX1. The external ambient temperature was also recorded. Thermocouple A has been positioned at the centre of the unit between the two main heat producing components, the heatsink and the transformer. Thermocouple B has been positioned at the top of the unit above the IGBTs where the highest temperatures would be expected. Thermocouple C has then been placed at the bottom right of the unit to measure the temperature of the air around the control circuitry. Figure 1 shows the position of the three thermocouples.

The power is measured using a Yokogawa power meter (WT230 – Serial Number: 91H833216), and the temperature has been measured using a National Instruments CompactDAQ system (cDAQ – 9172 – Serial Number: 1220172) with Thermocouple input modules (NI 9211). The test set up can be seen in Figure 2.

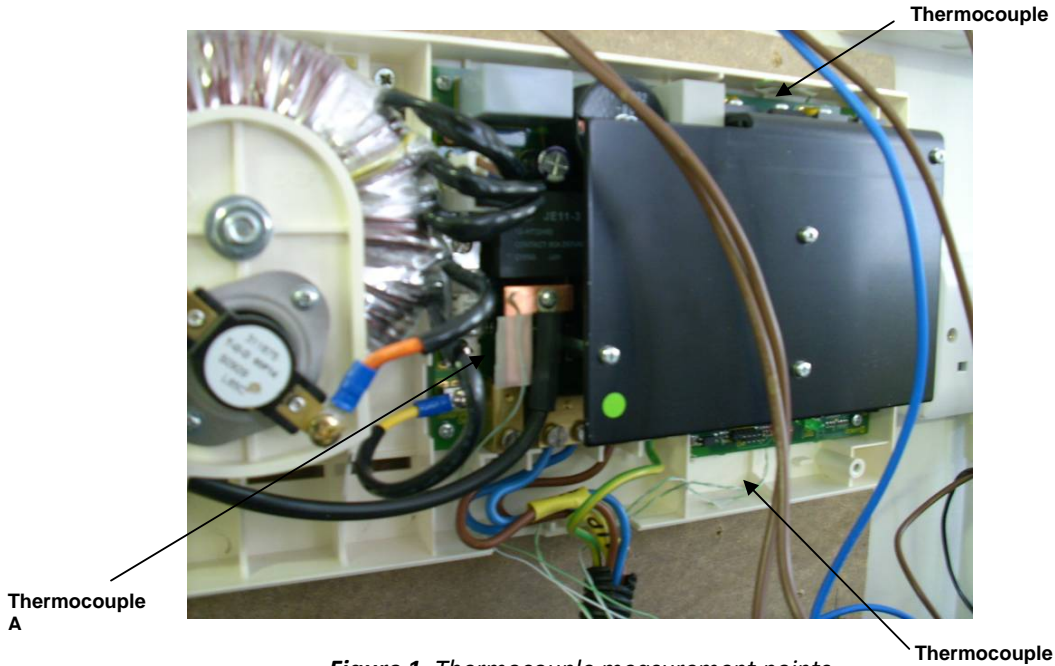


Figure 1. Thermocouple measurement points

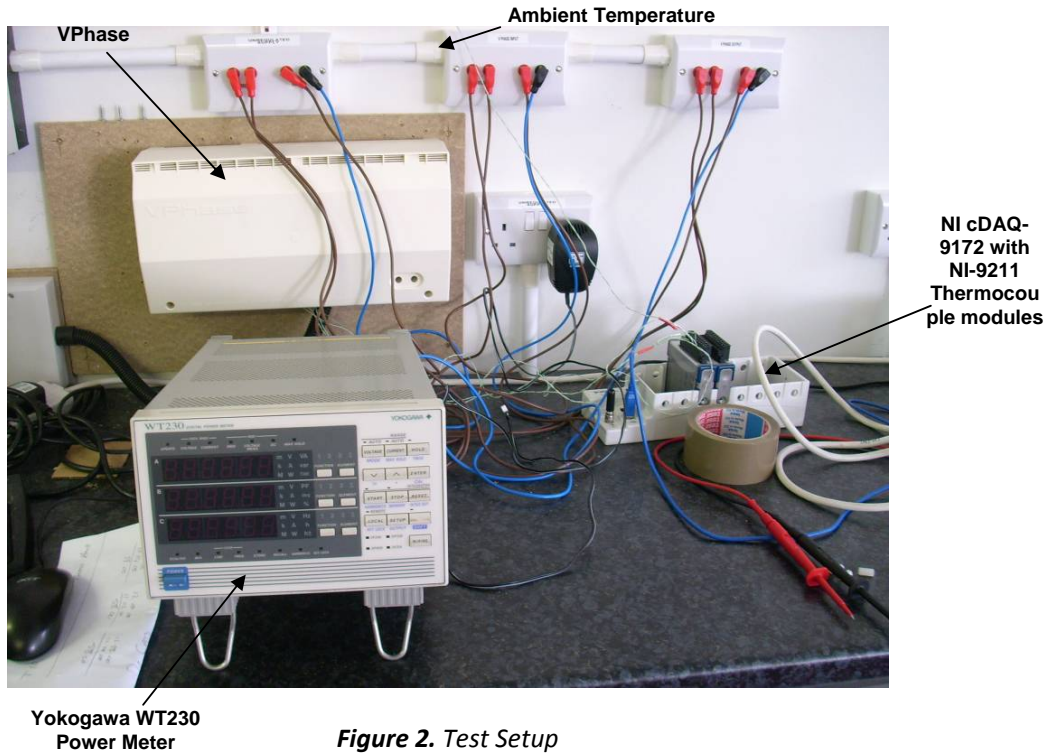


Figure 2. Test Setup

The value of 1kW has been chosen as the test load as this best represents the typical continuous load that the unit would see during its lifetime.

The VX1 is designed to regulate the base load of a property, and handle short transients. The VX1 does not supply power to the high power heating loads such as Electric Showers, Electric Cookers,

Immersion Heaters and Storage Heaters. The VX1 supplies power to socket outlets and lighting circuits.

If the base load of a property was at 1kW continuously all year then the expected electricity consumption would be 8760kWh, which would equate to an electricity bill of approximately £1050 (at 12p/kWh). As the average electricity consumption is closer to 4000kWh it is a good indication that the typical base load for a property is actually lower than 1kW.

The VX1 was set to regulate the output voltage to 220v at 1kW for 3 hours to let the internal temperatures stabilise. The final temperatures recorded for thermocouples A, B, C, and the ambient temperature are shown in Table 1.

**Table 1. Power and temperature data**

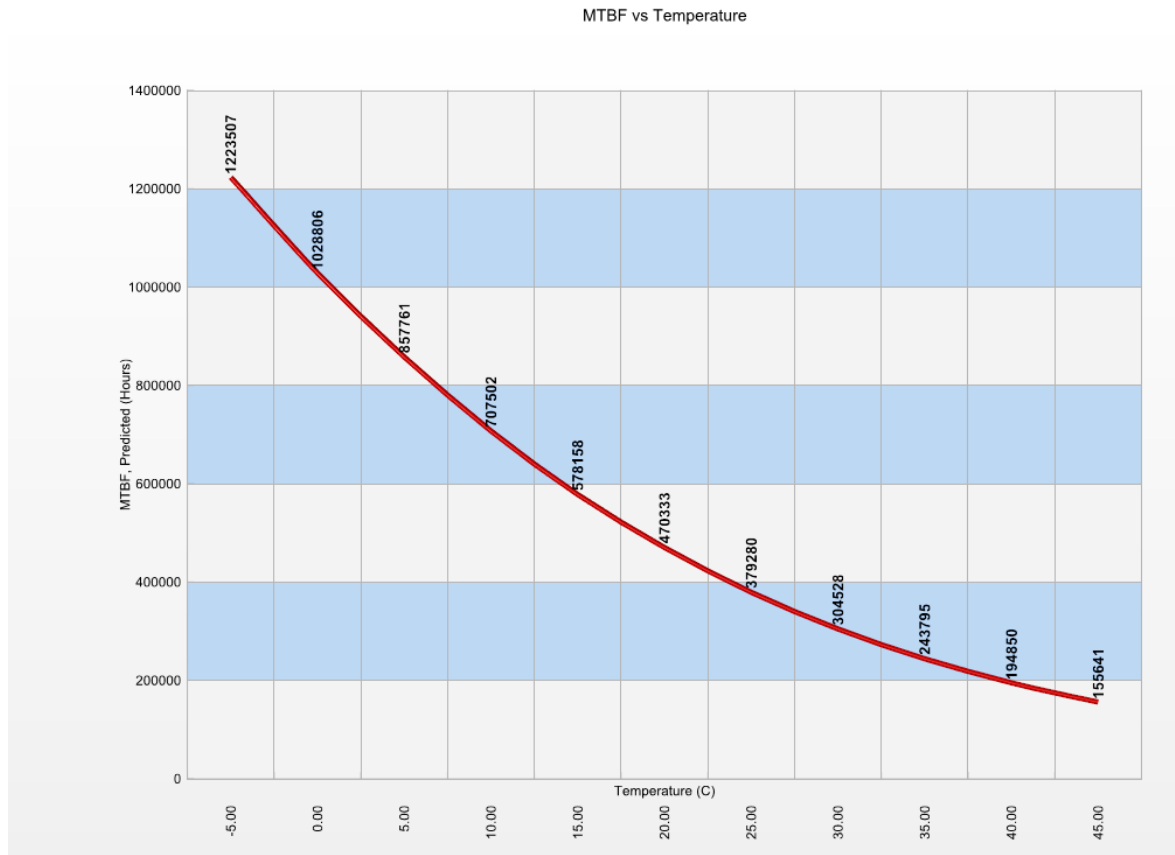
| Date       | VX1 Input |       |                        | VX1 Output |       |                         | Temperatures (°C) |                |                |                  |
|------------|-----------|-------|------------------------|------------|-------|-------------------------|-------------------|----------------|----------------|------------------|
|            | Volts     | Amps  | Instantaneous Power(W) | Volts      | Amps  | Instantaneous Power (W) | Thermocouple A    | Thermocouple B | Thermocouple C | External Ambient |
| 2010/05/21 | 245.72    | 4.282 | 1052                   | 219.62     | 4.696 | 1031                    | 35.518795         | 39.946073      | 27.251406      | 24.107827        |

As expected, the temperature at the top of the unit was the hottest at 39.9°C. The temperatures shown on the x-axis of the MTBF vs Temperature graph, see Figure 3, indicate the internal temperature of the unit for an assumed external ambient temperature of 21°C. The measured ambient temperature was 24.1°C, so the temperature measured by Thermocouple B needs to be adjusted by 3.1°C to compensate for the higher measured ambient temperature before the lifetime can be calculated from Figure 3. Therefore, given an external ambient temperature of 21°C, we would find the actual temperature measured by thermocouple B would be 36.8°C. Similarly, the temperature measured by thermocouple A is 32.4°C when adjusted to take into account the ambient temperature.

Taking the adjusted worst case temperature, 36.8°C and applying it to Figure 3 we find that the predicted lifetime of the unit will be 26.6 years. To calculate this value an assumption is made that line between the temperatures 35°C (243795 hrs) and 40°C (194850 hrs) is linear. The lifetime in hours for the temperature 36.8°C can then be extrapolated from the two data points.

Thermocouple B measures the worst case scenario, whereas thermocouple A is measuring the centre of the unit and would provide a better average temperature measurement for the control board. The adjusted temperature for Thermocouple A is 32.4°C, so extrapolating between the two data points for 30°C and 35°C we find that the predicted lifetime would be 38.1 yrs (333679.84 hrs).

Using these two temperatures we can state a worst case scenario of a 26.6 year lifetime, and a more likely 38.1 year lifetime.



**Figure 3.** MTBF vs Temperature

### Summary

A number of small changes have been made to the bill of materials since the Relx report was compiled. These changes were made in order to get through the EMC testing. The effects of these changes has been minimal on the calculated lifetime as the FIT values of the components are very similar or better, and where the FIT values are worse the components have had their ratings increased to reduce the stress upon them.

The Relx report concludes with a predicted lifetime for the unit. The lifetime of the unit is calculated as a function of the temperature, and based on the measured worst case temperature of 36.8°C (adjusted for ambient temperature) the Vphase VX1 will have a predicted lifetime of 26.6 Years.

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## Appendix 8 EA Technology VX1 Temperature Calculation

The following Table presents our extrapolated temperature estimates for the VX1 device.

Notes:

Load (kW) = property demanded power

Thermal Loss (W) = energy dissipated in the device (8W plus 1% of throughput)

Scale Factor = the proportion of load to the temperature measurement base at load 1kW

Temp. Rises = the temperature rise above ambient, which corresponds to the Figure on Page 11 of the Relex Report, Appendix 6.

**Table 15: Site 60 Temperature Calculations**

| Load (kW) | Load + Loss (W) | Scale Factor | Temp. Rise(K) | Temp. Top(°C) |
|-----------|-----------------|--------------|---------------|---------------|
| 0.0       | 8               | 0.44         | 7.5           | 27.4          |
| 0.2       | 10              | 0.56         | 9.4           | 29.3          |
| 0.4       | 12              | 0.67         | 11.2          | 31.2          |
| 0.6       | 14              | 0.78         | 13.1          | 33.1          |
| 0.8       | 16              | 0.89         | 15.0          | 35.0          |
| 1.0       | 18              | 1.00         | 16.8          | 36.8          |
| 1.2       | 20              | 1.11         | 18.7          | 38.7          |
| 1.4       | 22              | 1.22         | 20.6          | 40.6          |
| 1.6       | 24              | 1.33         | 22.5          | 42.5          |
| 1.8       | 26              | 1.44         | 24.3          | 44.4          |
| 2.0       | 28              | 1.56         | 26.2          | 46.2          |

|                          |             |             |
|--------------------------|-------------|-------------|
| <b>Mean Temp Site 60</b> | <b>10.9</b> | <b>29.0</b> |
|--------------------------|-------------|-------------|

*Note: Highlighted cells indicate measurements by VPhase, other cells are extrapolations*

## Appendix 9 Electrical Energy Saving Effect on Whole-House Carbon Emissions

The following Table calculates the effect of the electricity savings from the VX1 device on a percentage of estimated whole house (gas plus electricity) carbon emissions in the Reading area where the trial was carried out.

**Table 16: Whole-House CO<sub>2</sub> Saving for the Trial**

|   | Reading<br>(DECC <sup>8</sup> , kWh) | Trial<br>(kWh) | kgCO <sub>2</sub> /kWh | kgCO <sub>2</sub> |
|---|--------------------------------------|----------------|------------------------|-------------------|
| <b>Electricity Consumed</b>                         | 4270                                 | 4592           | 0.591                  | 2714              |
| <b>Gas Consumed</b>                                 | 16505                                | 17748          | 0.206                  | 3656              |
| <b>Electricity Saved @ 5.2%</b>                     |                                      | 238            | 0.591                  | 141               |
| <b>Whole-House %-CO<sub>2</sub> emission saving</b> |                                      |                |                        | 2.21%             |

Whole-house emissions would be reduced by 2.2%. Note that this has been calculated using the percentage energy saving from the trial, hence it applies to a mass rollout and not to individual installations of the device.



## Appendix 10 Results Adjusted to Reflect Percentage Energy Savings Without Electric-Heating Appliances

### Electric Heating in the Trial

The trial was supposed to take place at sites where electric heating was not in use, as voltage optimisation devices do not realise savings for applications requiring fixed amounts of energy. These include uses of electricity for thermostatically-controlled heating such as immersion heaters, electric showers, electric hobs and ovens.

During the site selection process, 'no electric heating' was taken to mean that the main source of home heating should not be electric. Thermostatically-controlled heating was thus found to be present at many of the trial sites. The client has asked that the results be re-presented to take account of the portion of electrical load that is thermostatically-controlled, which has been defined as the aforementioned immersion heaters, electric showers, electric hobs and ovens.

In any property, there are loads which are supplied through the VX1 and those which are supplied direct from the consumer unit. Electric heating loads should be supplied direct from the consumer unit, since otherwise, they would increase load on the VX1 and increase the amount of time that it spends in the bypass mode of operation. No energy savings can be made for connected loads when in bypass. Energy demand measured at these sites will be higher than if electric heating loads were not present. In this Appendix the extra electric heating load is removed from these sites, based upon UK average energy consumption for different classes of appliances.

The effect of this re-presentation is to slightly raise the percentage energy saving attributable to the VX1 at those sites where electric heating was in use. There is no change to the absolute quantities of energy saved or carbon abated.

### Data Sources and Assumptions

Some 8.7% of homes in England use electricity for space heating<sup>19</sup>; the corresponding figure for Scotland is believed to be significantly higher, at circa 25% of households.

Detailed disaggregated energy consumption statistics were also obtained from DECC<sup>18</sup>, the English House Condition Survey 2005<sup>19</sup>, and the European Commission<sup>20</sup>, for further analysis. Data could not be obtained for the energy consumption of immersion heaters in properties where the main source of home heating was not electric. Data on the ownership of electric showers was obtained from the Energy Saving Trust<sup>21</sup>.

Data could not be obtained for the energy consumption of electric showers, the following assumption has been made:

Additional energy consumed at properties with electric showers (kWh/year) = 8.5kW \*15 minutes/per day \*365 days/year.

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<sup>18</sup> DECC, Energy Consumption in the UK, Domestic Data Tables 2010 Update, available at [www.decc.gov.uk](http://www.decc.gov.uk), accessed 7<sup>th</sup> September 2010

<sup>19</sup> Dept. for Communities and Local Government, Energy Use in Homes 2005, published 2008.

<sup>20</sup> European Commission Joint Research Centre, Electricity Consumption and Efficiency Trends in the Enlarged European Union, Status Report 2006, available at [www.re.jrc.ec.europa.eu/energyefficiency](http://www.re.jrc.ec.europa.eu/energyefficiency)

<sup>21</sup> The Energy Saving Trust, The Rise of the Machines, available at [www.energysavingtrust.org.uk](http://www.energysavingtrust.org.uk), accessed 7<sup>th</sup> September 2010

Showers are available in capacities ranging from 6 to 10kW, with 8.5kW being common.

### Full Report

This Appendix contains energy consumption statistics which were obtained for VPhase and are part of a report which has been prepared by EA Technology. A copy of this report can be provided by VPhase upon request.

### Tables and Figures

Table 17 presents the results of this research into UK energy consumption and the scale factors which should be applied to the percentage energy savings of sites in the trial, depending on the type of electric heating present.

Table 18 presents the types of electric heating present at each site and rebased per-site percentage energy savings.

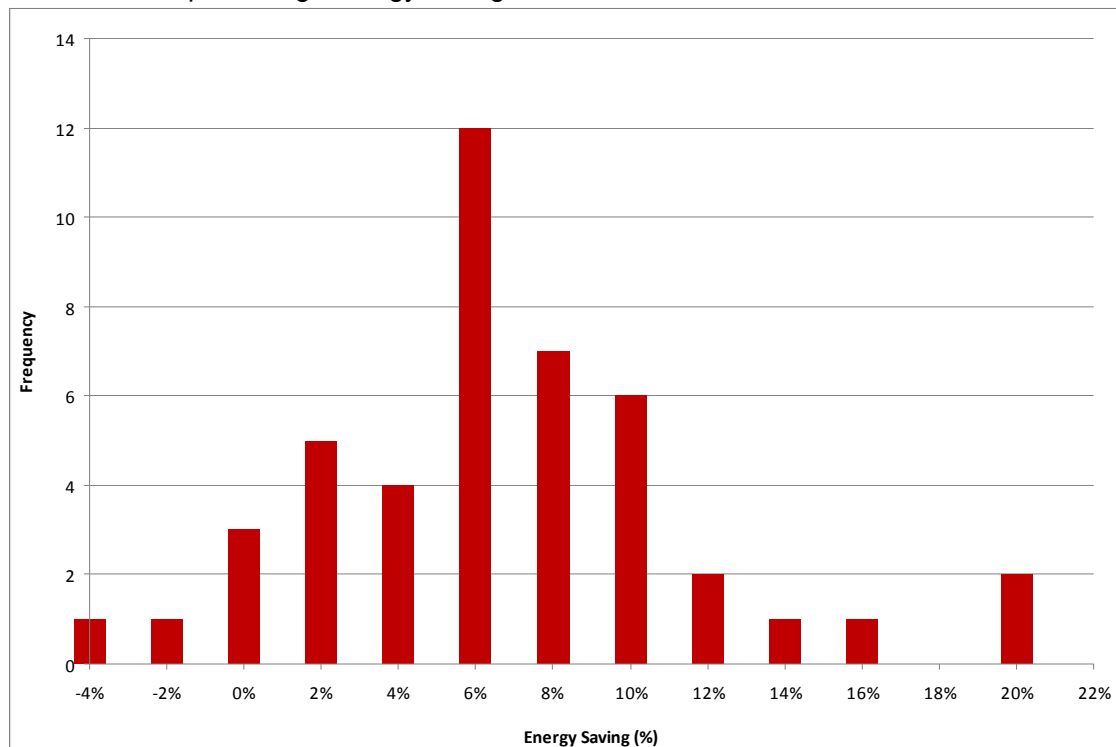
Table 19 presents rebased percentage energy savings and compares to the original results.

Figure 22 presents the percentage energy savings in histogram format.

### Summary

Data was obtained which enabled the percentage of UK energy consumption arising from different appliances to be calculated. Based upon this breakdown, electric heating was removed from those sites where it had been present. Percentage energy saving results were rebased to non-electric heating homes, which resulted in an increase of the percentage mean energy saving for the trial as a whole, to 6.3%.

Almost 50% of percentage energy savings were between 8% and 10%.



**Figure 22: Percentage Energy Savings of Rebased Results**

Note x-axis label denotes the lower end of the bin, i.e. there were 3 results which were between 0% and 2%.

**Table 17: Estimated Energy Consumption of Sites with Electric Heating**

|                              | <b>Appliance Category</b>   | <b>Percentage of UK Energy Consumption</b> | <b>Gas for All Cooking and Hot Water</b> | <b>Electric Immersion Only</b> | <b>Electric Cooking Only</b> | <b>Electric Shower and Electric Cooking</b> | <b>Electric Immersion and Cooking</b> | <b>Electric Immersion, Cooking and Shower</b> | <b>Electric Immersion and Shower</b> |
|------------------------------|-----------------------------|--|--|--------------------------------|------------------------------|---|---------------------------------------|---|--------------------------------------|
| <b>VX1-Supplied Load</b>     | Lighting                    | 13%  | y  | y                              | y                            | y   | y                                     | y   | y                                    |
|                              | Cold appliances             | 12%  | y  | y                              | y                            | y   | y                                     | y   | y                                    |
|                              | Wet appliances              | 12%  | y  | y                              | y                            | y   | y                                     | y   | y                                    |
|                              | Consumer electronics        | 18%  | y  | y                              | y                            | y   | y                                     | y   | y                                    |
|                              | Computing equipment         | 5%   | y  | y                              | y                            | y   | y                                     | y   | y                                    |
|                              | Other cooking utensils      | 6%   | y  | y                              | y                            | y   | y                                     | y   | y                                    |
| <b>Non-VX1 Supplied Load</b> | Electric cooking            | 11%  | n  | n                              | y                            | y   | y                                     | y   | n                                    |
|                              | Space heating               | 7%   | n  | n                              | n                            | n   | n                                     | n   | n                                    |
|                              | Electric showers            | 16%  | n  | n                              | n                            | y   | n                                     | y   | y                                    |
|                              | Electric immersion          | 0.0%                                       | n  | y                              | n                            | n   | y                                     | y   | y                                    |
| <b>Ratios of Loads</b>       | VX1-Supplied Loads          |  | 66%                                      | 66%                            | 66%                          | 66%   | 66%                                   | 66%   | 66%                                  |
|                              | Non-VX1-Supplied Loads      |  | 0.0%                                     | 0.0%                           | 11.0%                        | 27.0%                                       | 11.0%                                 | 27.0%   | 16.0%                                |
|                              | Scale Factor to Gas for All |  | 100%                                     | 100%                           | 117%                         | 141%  | 117%                                  | 141%  | 124%                                 |

Note: "y" or "n" denotes the presence or absence of the appliance in each category of property.

**Table 18: Trial Results Rebased to Properties Without Electric Heating**

| Site Ref | Electric Immersion | Electric Cooking | Electric Shower | CERT Trial Result | Rebased Result |
|----------|--------------------|------------------|-----------------|-------------------|----------------|
| 1        | y                  | y                |                 | 3.8%              | 4.4%           |
| 2        | y                  | y                |                 | 7.4%              | 8.6%           |
| 3        |                    | y                |                 | 13.3%             | 15.5%          |
| 4        |                    | y                | y               | 18.8%             | 26.5%          |
| 5        |                    | y                |                 | 7.2%              | 8.4%           |
| 6        |                    | y                | y               | 7.9%              | 11.2%          |
| 7        |                    | y                |                 | 16.5%             | 19.3%          |
| 8        | y                  | y                |                 | 2.8%              | 3.3%           |
| 9        |                    |                  |                 | 6.5%              | 6.5%           |
| 10       | y                  |                  |                 | 5.8%              | 5.8%           |
| 12       | y                  | y                |                 | 9.2%              | 10.8%          |
| 13       |                    | y                |                 |                   |                |
| 14       | y                  | y                | y               | 1.8%              | 2.6%           |
| 15       |                    | y                |                 | 5.0%              | 5.8%           |
| 16       |                    | y                |                 | 5.0%              | 5.9%           |
| 17       | y                  | y                |                 | 5.6%              | 6.5%           |
| 19       |                    |                  |                 | 7.2%              | 7.2%           |
| 20       | y                  | y                |                 | 11.4%             | 13.3%          |
| 21       |                    |                  |                 | 5.9%              | 5.9%           |
| 22       |                    |                  |                 | 0.2%              | 0.2%           |
| 23       | y                  |                  |                 | 0.7%              | 0.7%           |
| 24       | y                  | y                | y               |                   |                |
| 26       |                    |                  |                 |                   |                |
| 27       | y                  | y                | y               | 3.7%              | 5.2%           |
| 32       | y                  |                  |                 | 8.7%              | 8.7%           |
| 33       | y                  | y                | y               | 5.8%              | 8.2%           |
| 37       | y                  | y                |                 | -2.8%             | -3.3%          |
| 38       | y                  |                  | y               | 2.7%              | 3.4%           |
| 39       |                    | y                | y               |                   |                |
| 42       | y                  | y                | y               | 3.1%              | 4.4%           |
| 48       | y                  | y                |                 | 1.3%              | 1.5%           |
| 50       |                    | y                | y               | 3.1%              | 4.4%           |
| 54       | y                  | y                | y               |                   |                |
| 56       | y                  | y                |                 | 6.5%              | 7.5%           |
| 58       | y                  | y                |                 | 15.6%             | 18.2%          |
| 60       |                    | y                |                 | 5.1%              | 6.0%           |
| 64       | y                  | y                |                 | 0.4%              | 0.5%           |
| 65       | y                  | y                |                 | 6.2%              | 7.2%           |
| 67       | y                  | y                |                 | 4.2%              | 4.9%           |

|    |   |   |   |       |       |
|----|---|---|---|-------|-------|
| 68 | y | y |   | -1.3% | -1.5% |
| 70 |   | y |   | 4.6%  | 5.4%  |
| 72 |   | y | y | 6.6%  | 9.3%  |
| 73 |   | y |   | 5.4%  | 6.3%  |
| 79 |   |   |   | 2.1%  | 2.1%  |
| 80 | y | y | y | 3.8%  | 5.3%  |
| 83 | y | y | y | 4.6%  | 6.4%  |
| 90 | y | y |   | 1.1%  | 1.3%  |
| 93 |   | y | y | 6.7%  | 9.4%  |
| 95 | y | y |   | -3.9% | -4.6% |
| 97 |   | y |   | -1.6% | -1.9% |

**Table 19: Percentage Mean Energy Saving**

|   | <b>Trial</b> | <b>Rebased</b> |
|---|--------------|----------------|
| <b>Mean Electricity % Saving</b>                  | 5.2%         | 6.3%           |
| <b>Number of Sites</b>                            | 45           | 45             |
| <b>Standard Deviation of Site Energy Saving %</b> | 4.7%         | 5.8%           |
| <b>CL ± %</b>                                     | 1.4%         | 1.7%           |