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Energy Saving Trial Report for the 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_2 per household, over the estimated 36 year lifetime of the device, based upon the reference carbon emissions factor of 0.591 kgCO_2/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.

Contents

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 ±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[1]. 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.

[1] 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[2] 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.

[2] 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[3] 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 ±1.0%, using “IME TM2U” voltage transducers[4].

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.

[3] AMPY Type 5235B
[4] Datasheet available from 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[5]
4	Property Type	Bungalow Terrace Semi Detached Flat	Questionnaire Responses
5	Property Age	Construction Decades	Questionnaire Responses
6	Location	City Town Suburbs Rural	Postcodes and CAMEO[6] 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

[5] SEC is a division of SSE
[6] 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[7].

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[8].

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
Small terrace	5
Large terrace	9
Semi	14
Detached	9
Bungalow	5
Converted flat	2
Low rise flat	6
High rise flat	0
Total	50

Trial Property Type	EHCS Number	Achieved
Terraces	14	13
Semi	14	16
Detached	9	16
Bungalow	5	2
Flats	8	2
Unknown		1
Total	50	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.

[7] As previously submitted by VPhase in documents to Ofgem, prior to the trial
[8] DECC, Electricity consumption at regional and local authority level 2008, available at www.decc.gov.uk, accessed 31/03/2010. Value is a UK average and includes electrically-heated properties.

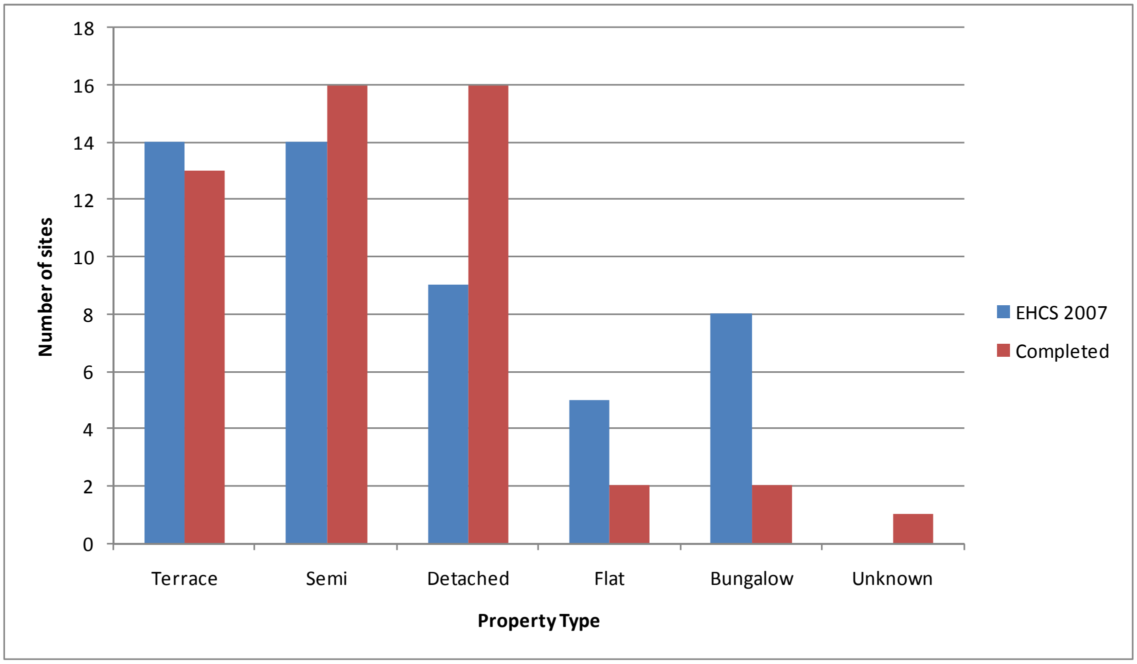


Figure 1: Trial Property Types

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
Total	**50**	**50**

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.

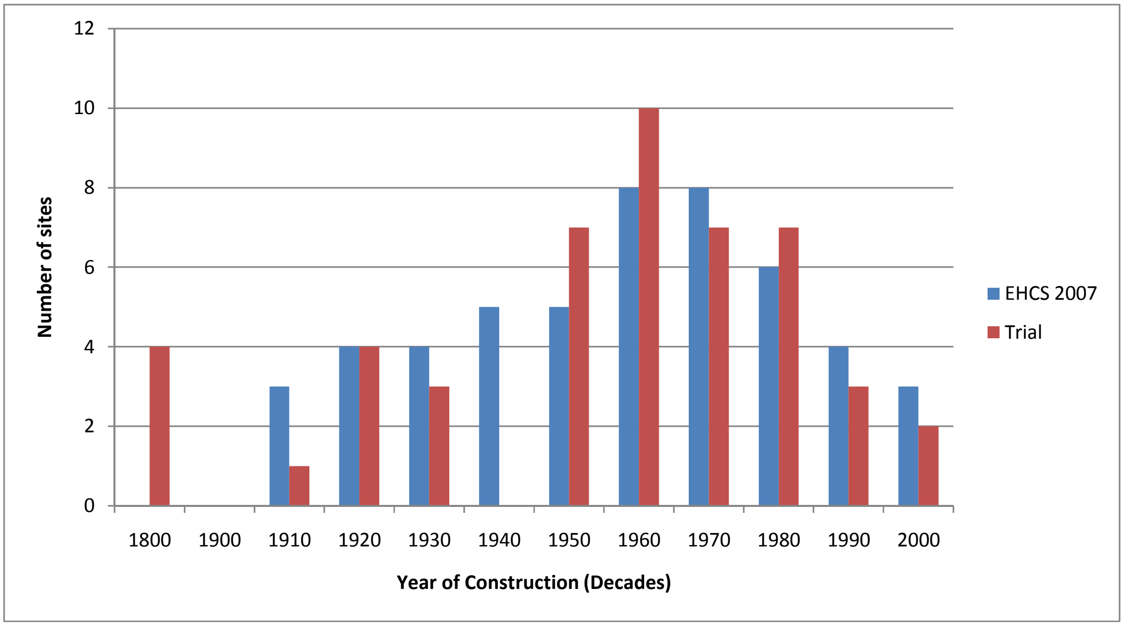


Figure 2: Trial Site Property Age

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

	EHCS			EHCS' (Ideal Trial)
City Centre	2		City	2
Other Urban centre	17		Town	19
Suburban Residential	13	→	Suburbs	13
Rural Residential	11		Rural	16
Village Centre	4			
Isolated Rural	3			
Total	**50**		**Total**	**50**

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

	CAMEO			CAMEO' (Achieved)
City/Suburbs	0		City	0
Town/Suburbs	11		Town	5.5
Suburbs/Rural	33	→	Suburbs	25
Rural	1		Rural	17.5
Suburbs	3		Unknown	2
Unknown	2			
Total	**50**		**Total**	**50**

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.

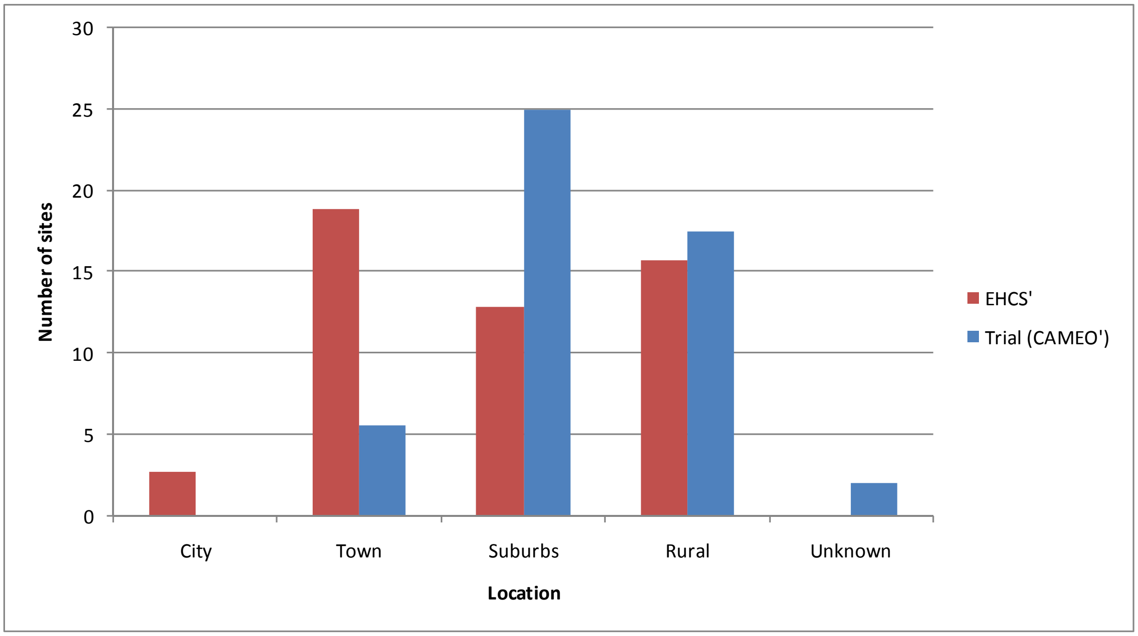


Figure 3: Trial Site Locations

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.

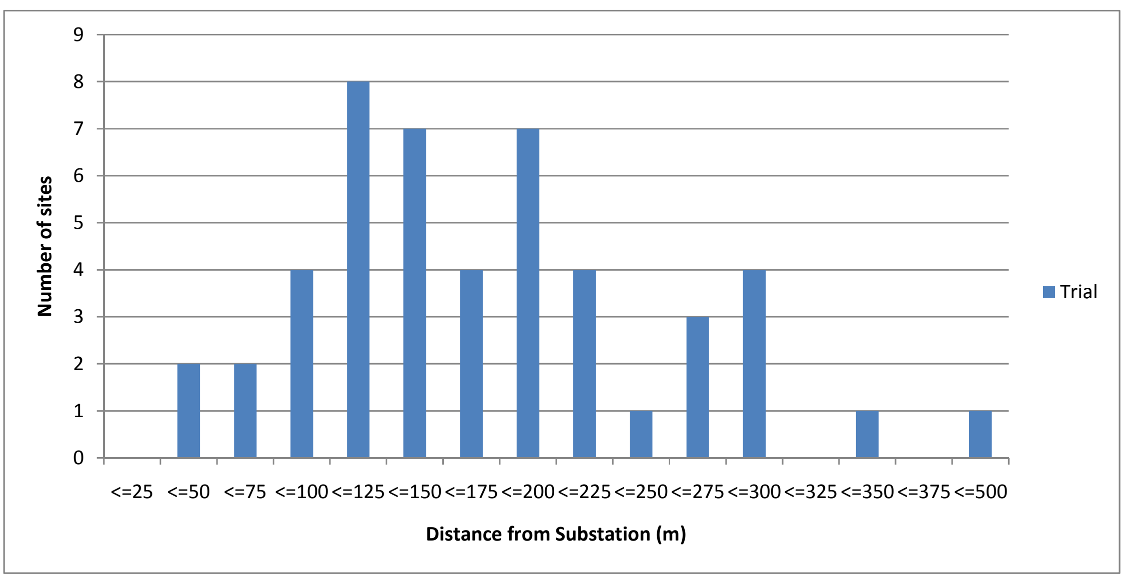


Figure 4: Trial Sites' Distances from Substations

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.

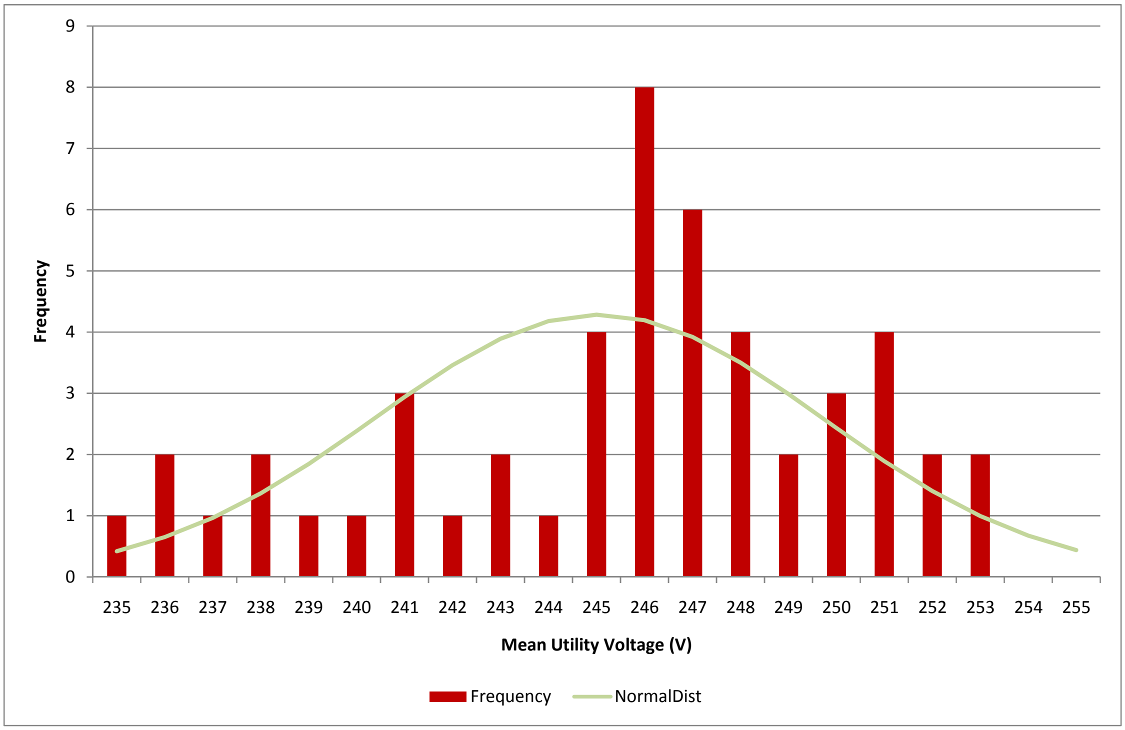


Figure 5: Trial Sites Mean Utility Voltage

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% ±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% ±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 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.

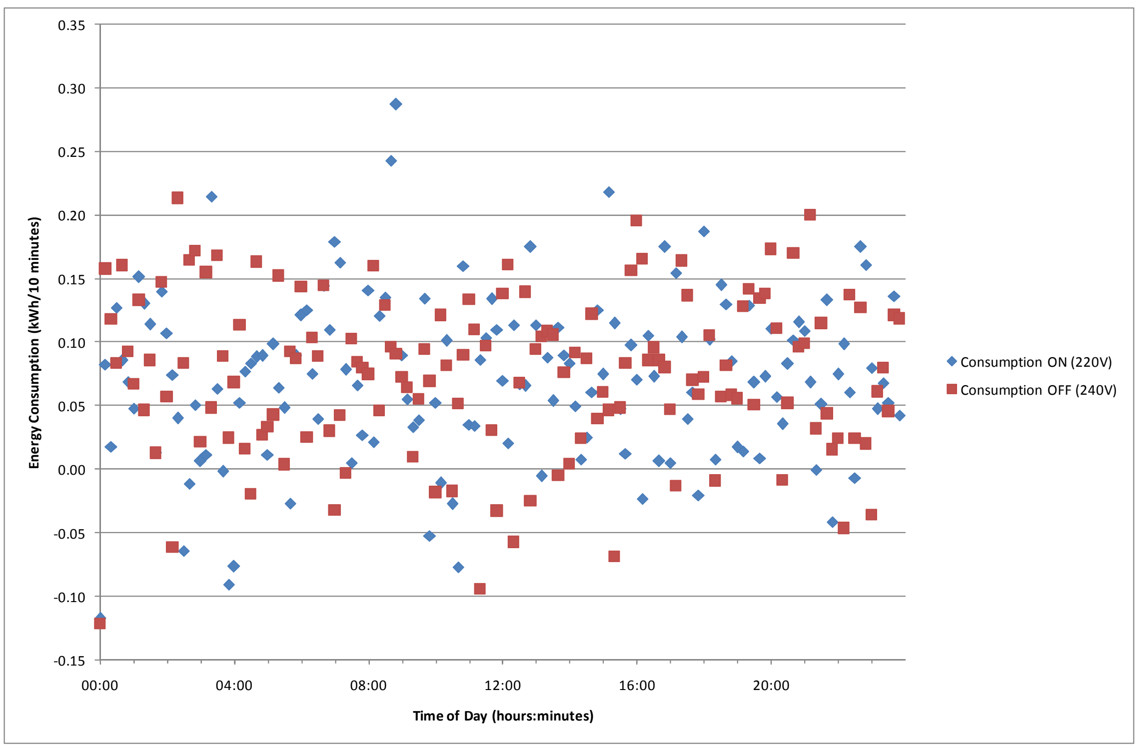


Figure 6: Indicative Consumption Profile for Robustness Tests

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[9]
	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

[9] 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[10] and estimated yearly energy consumption.

Table 9: Energy Consumption and Voltage Statistics

	Mean Utility Voltage (V)	Energy Consumption (kWh/year)
Max	253	12200
Mean	245	4590
Min	235	1320
Standard Deviation (across sites)	5	2360
Confidence Limit on Mean (±, across sites)	1	654

Mean utility voltage was determined to be 245 ±1V, with the maximum voltage being 253V and the minimum being 235V. Mean energy consumption was determined as 4590 ± 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 ±1.4%. This 5.2% mean value is used in all subsequent calculations.

[10] 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%	**5.2%**
Number of Sites in Algorithm	45	45	45	45	**45**
Standard Deviation of Energy Saving %)[11]	5%	5%	5%	5%	**5%**
Confidence Limit on Mean ± (%)[11]	1.4%	1.4%	1.3%	1.6%	**1.4%**

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.

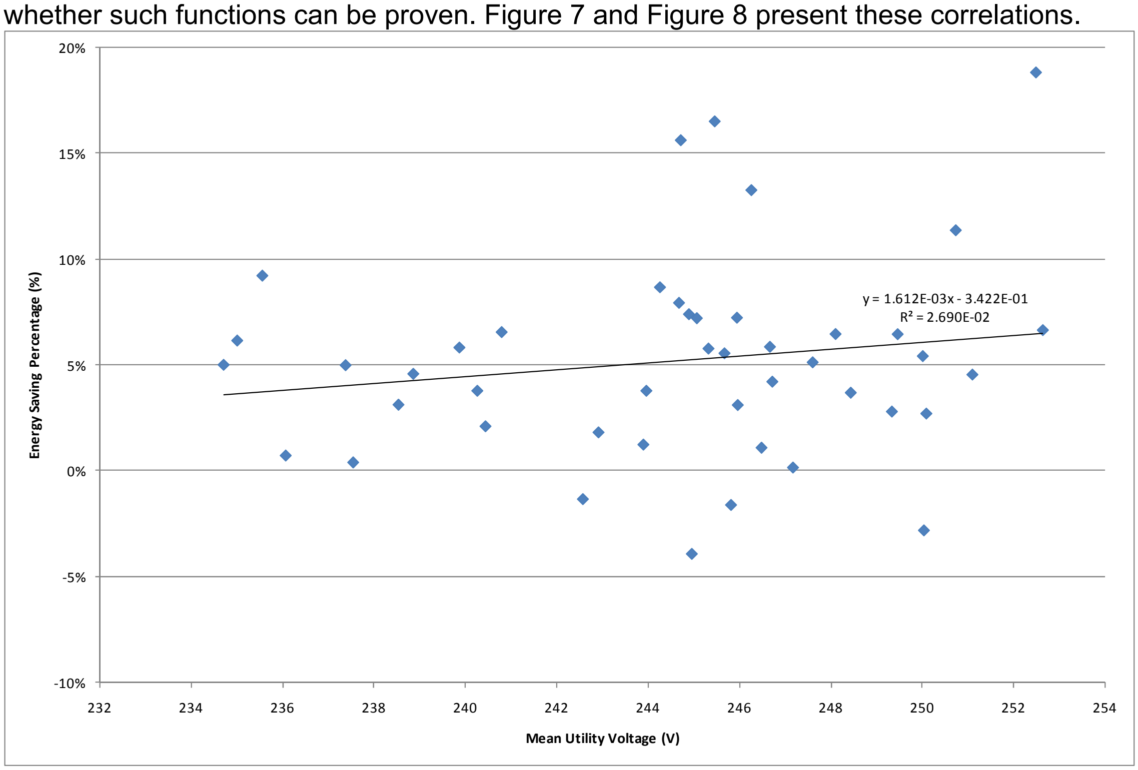


Figure 7: Correlation of Energy Saving Percentage with Mean Utility Voltage

[11] Standard deviations and confidence limits are expressed as percentage energy savings

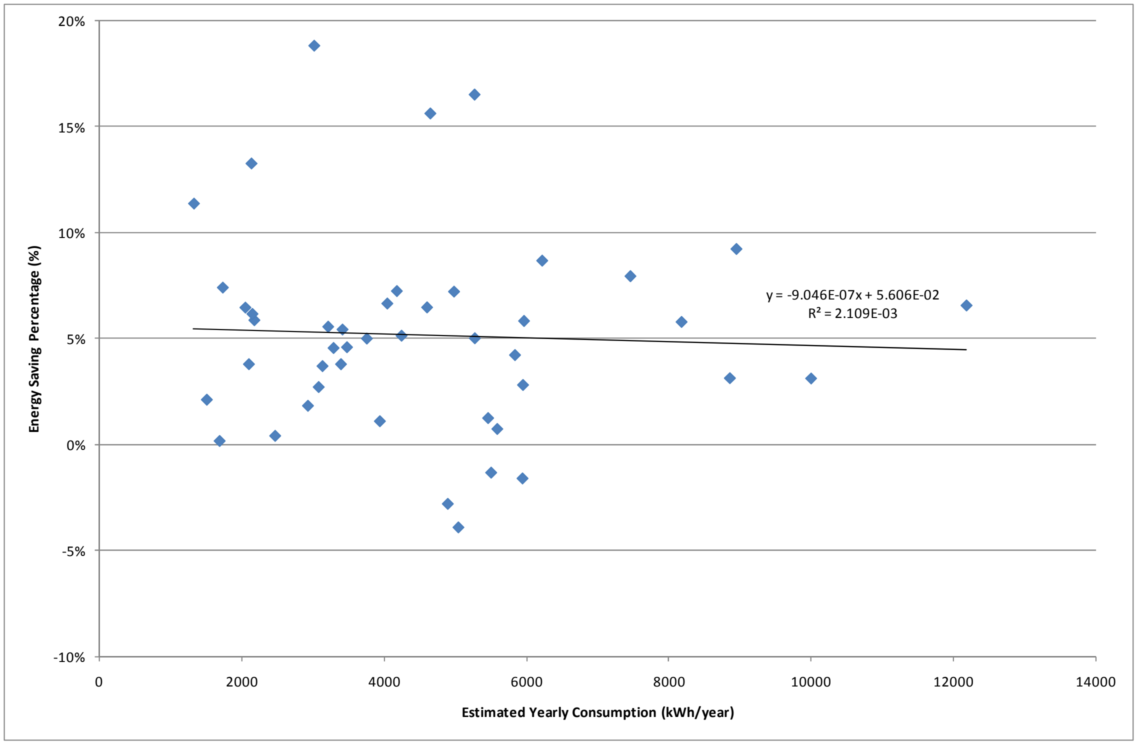


Figure 8: Correlation of Energy Saving Percentage with Estimated Yearly Consumption

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)[12], 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.

[12] 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.

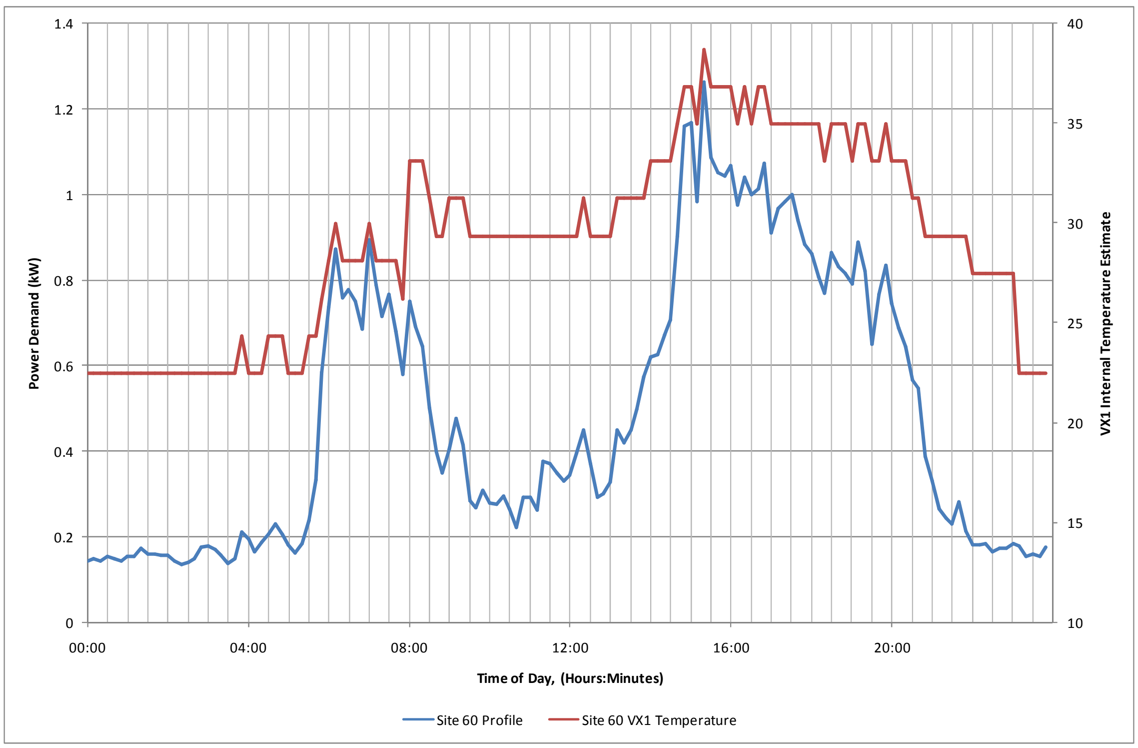


Figure 9: Power Demand Profile for Site 60, 4240kWh/year

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 29ºC, 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[13] 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 20ºC between the hours of 08:00 and 22:00 and 15ºC otherwise[14].
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 = 29ºC) and look up against Relex 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.

[13] 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.
[14] 20ºC set to match the Relex report, 15ºC set subjectively, for an assumed lower night-time ambient

Table 11: Carbon Emissions Factors

Source	Date	Value ($kgCO_2/kWh$)	Notes
Building Research Establishment SAP[15]	March 2009	0.591 (Use and Savings)	Includes whole emissions from ore extraction to consumption plus the effects of emissions of other pollutants 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 ($kgCO_2$) = trial mean energy saving (%) * UK average consumption (kWh/year) * duration of the energy saving (years) * carbon emissions factor ($kgCO_2/kWh$)

The sources of each parameter are listed in Table 12, together with the carbon abatement value, which is 5.0 tCO_2 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[8]	4478 kWh/year
Duration of the Energy Saving	Years	Relex Reliability Report / EA Technology Calculation	36 years
Carbon Emissions Factor of Electricity	$kgCO_2/kWh$	BRE SAP 2009	0.591
		Carbon Abatement (tCO_2)	**5.0**

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.

[15] 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 VXI devices, was determined from the trial as 5.2%, with a confidence limit on the mean of ± 1.4%.

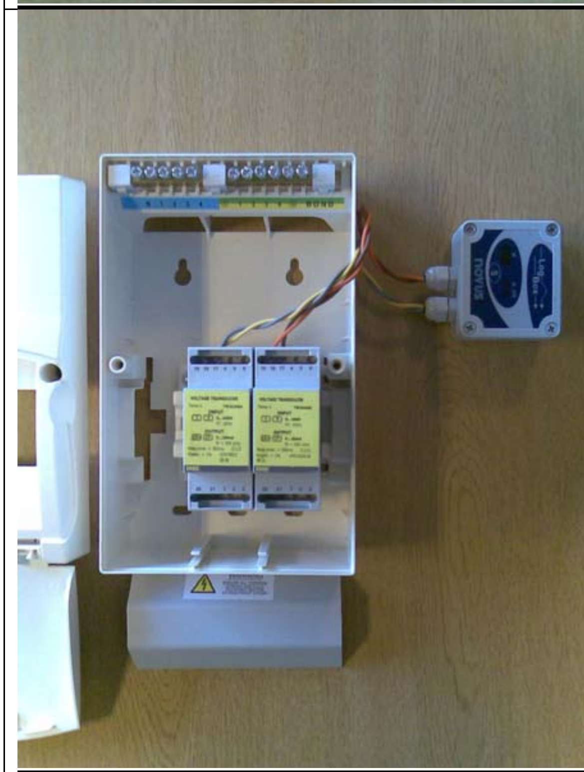
8.9 The lifetime of a typical VX1 device was predicted to be 36 years, based upon independently-assessed estimates of reliability, measurements made by the manufacturer and data acquired during the trial itself.

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.

	**Monitoring Kit Contents** 4-way consumer unit containing: Pulse logger Voltage logger Connection diagram Voltage transducers Serial number
	**4-way consumer unit containing voltage logging equipment**.

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

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% 12.8%±16% -4.5% ±21% 8.5% ±20% *Average* 5.2%	4.1% ±0.0%[16] 14.6%±0.0% -4.4 %±0.0% 9.1% ±0.0% *Average* 5.9%	4.0% 12.7% -4.6% 8.3% *Average* 5.1%	4.9% 18.7% 7.6% 11.1% *Average* 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% 4.5% ±0.1% 4.9% ±0.2%	4.6% ±0.0% 4.7% ±0.0% 5.2% ±0.0%	4.4% 4.6% 5.2%	4.6% 4.8% 5.5%
4	Holiday (7-day holiday in middle of dataset, standard deviation set to zero)[17]	4.3% ±0.1%	4.5% ±5.0%	3.6%	4.5%

[16] 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

[17] 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

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

State	OFF/Inactive
Note	No-load

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 ±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 Toggling daily 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 Toggling daily 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 Toggling daily 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 Toggling daily Load constant 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 Toggling daily Load reducing slightly 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 Electric heating started after 30th (high base load for from 30/01/2010 to 04/03/2010) Toggling daily 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 Toggling daily 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 Toggling daily Load reducing over time 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 Toggling daily 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 Toggling daily Voltage traces were transposed, have been corrected 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 201/01/2010 to 14/03/2010 Toggling daily 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 Toggling daily Load reducing over time 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 Toggling every 2 to 3 days 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 Toggling daily 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 Toggling 2 to 3 days Load increasing 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 Toggling 2 to 3 days Load increasing 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 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 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 Toggling every 2 to 3 days Toggling is irregular, use Algorithm 2 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 Toggling daily after the 24th 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 Toggling daily Load reducing over time 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 Energy logger failed on 21/04/2010 so no useful data after 20/04/2010 Garage circuits were not connected to VX1, significant savings were expected on the freezer and garden pond pumps, which were in continuous running 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 Moved start to start of toggles and end to before a holiday period Toggling daily 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 Toggling 2 -3 days 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 Toggling daily 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 Toggling 2 to 3 days 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 Toggling daily 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 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 Toggling daily Load increasing 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 Toggling daily 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 Toggling 2 to 3 days at first then daily 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 Toggling daily from the 23rd (not previously) Load decreasing 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 Excluded a holiday period at the start of the data 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 Toggling daily from the 14th 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 Toggling daily Load increasing No toggling during the first two downloads 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 Toggling daily 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 Toggling daily 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 Toggling daily Load increasing Kerswell has quite low utility voltage, often 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 Reconstructed on/off days according to an early voltage measurement, later voltage measurements were not recorded 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 Toggling daily 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 Toggling 2 to 3 days Load increasing 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 Toggling daily Load reducing over time VPhase note that dining-room sockets, an unknown 16A circuit and shower pump were not connected to the VX1 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 Toggling daily after 17/03/2010 so used that as the start date Load reducing over time 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 Toggling daily 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 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 Toggling 2 to 3 days Load reducing 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 Toggling daily 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 Toggling 2 to 3 days 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 Toggling daily 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.

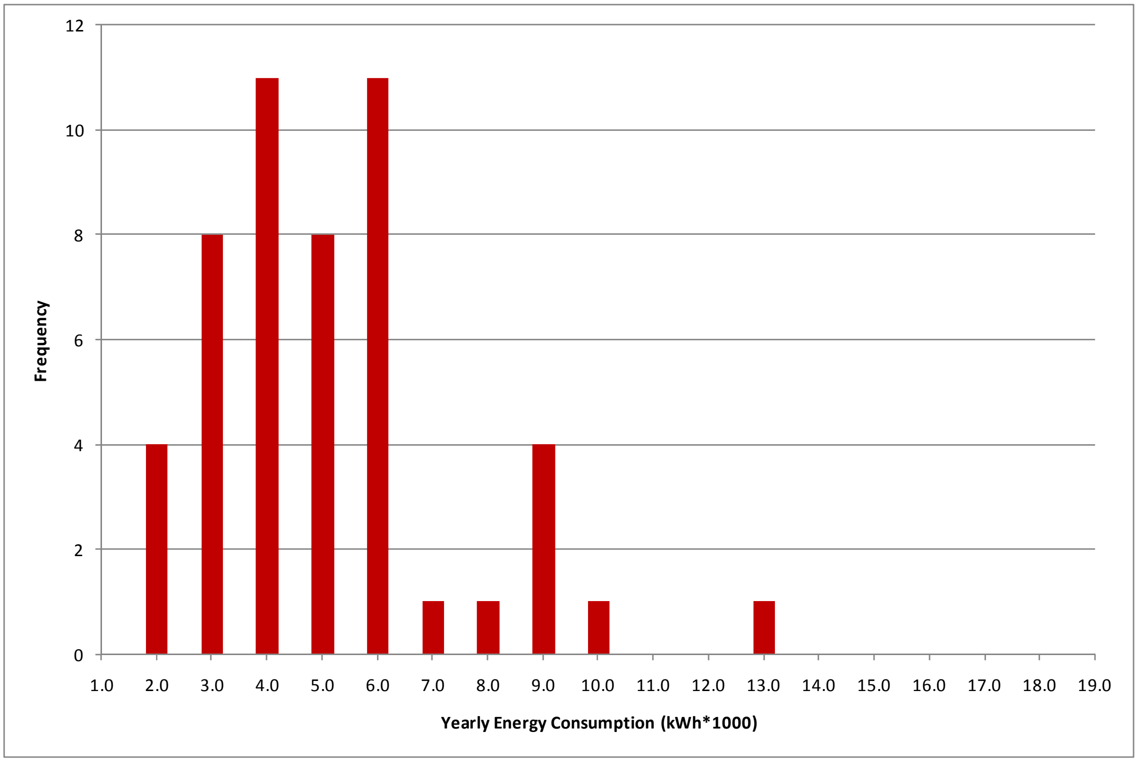


Figure 10: Distribution of Estimated Yearly Energy Consumption for Trial Sites

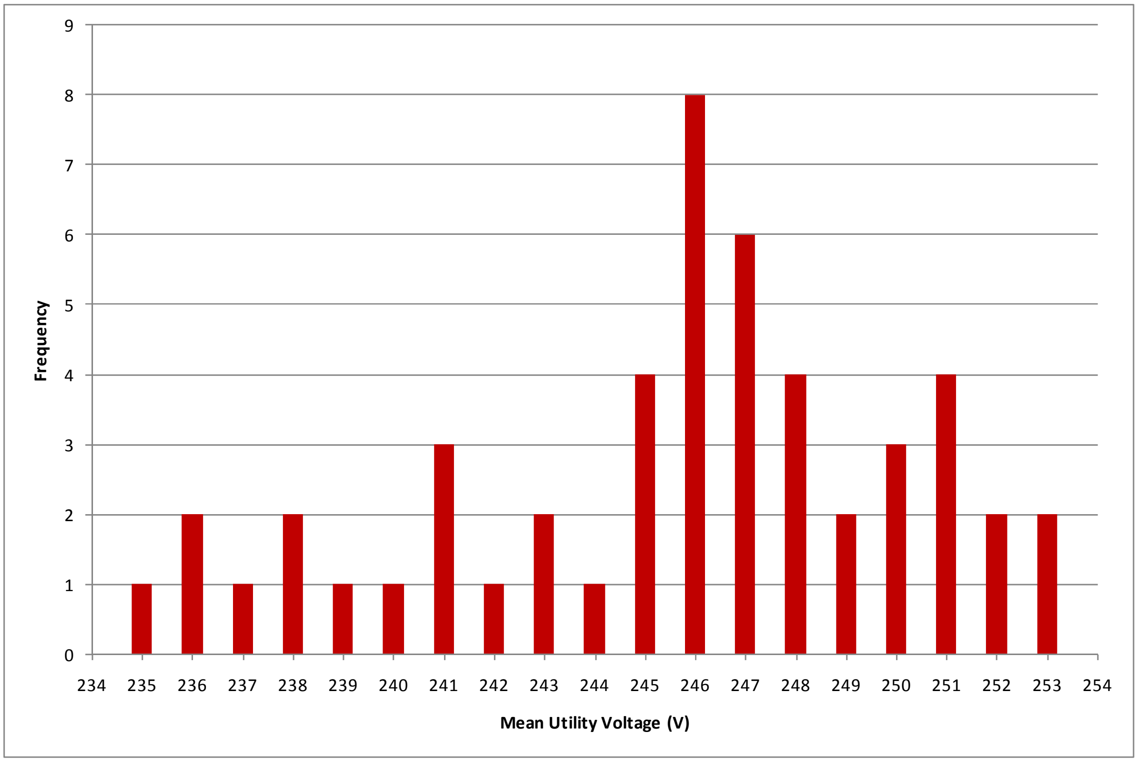


Figure 11: Distribution of Mean Utility Voltage for Trial Sites

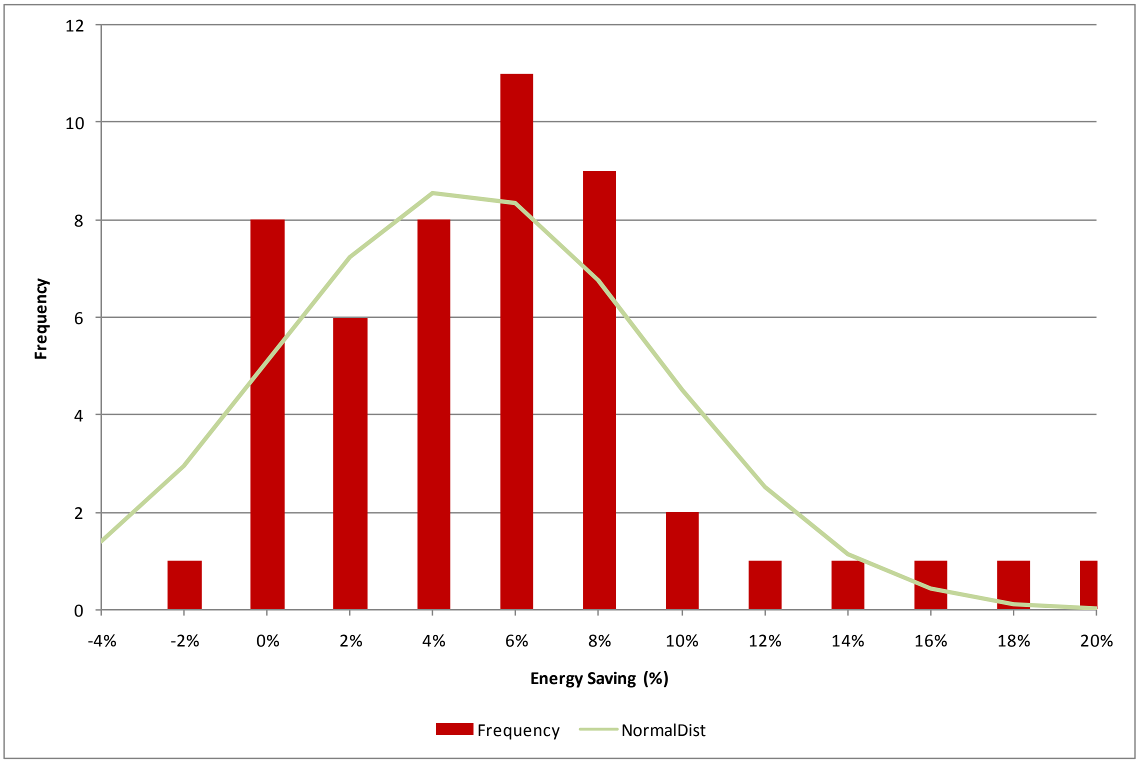


Figure 12: Distribution of Energy Saving Percentages for Trial Sites

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

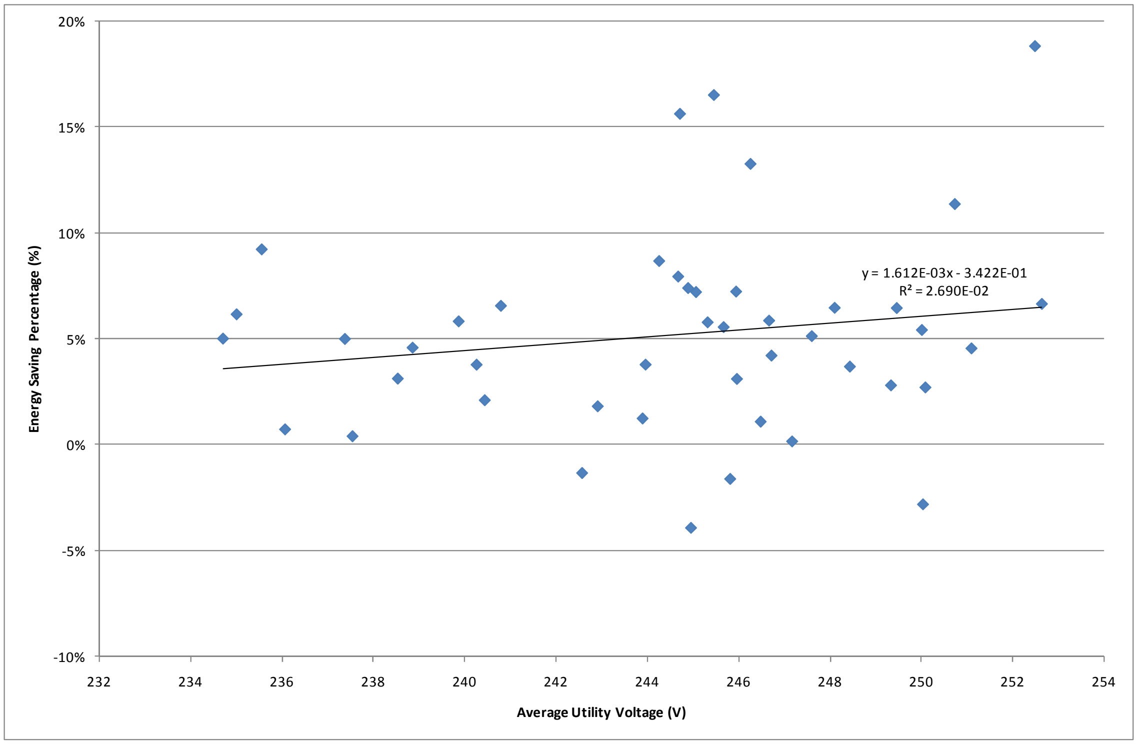


Figure 13: Correlation of Percentage Energy Saving with Mean Utility Voltage

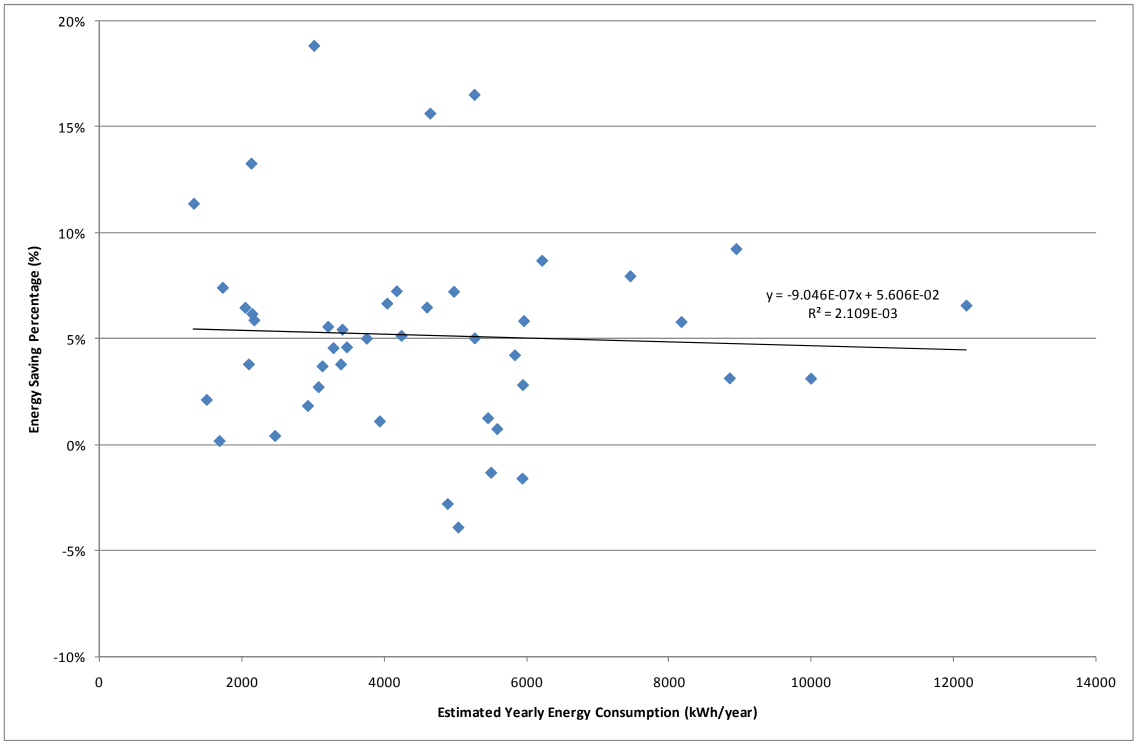


Figure 14: Correlation of Energy Saving Percentage with Estimated Yearly Energy Consumption

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

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

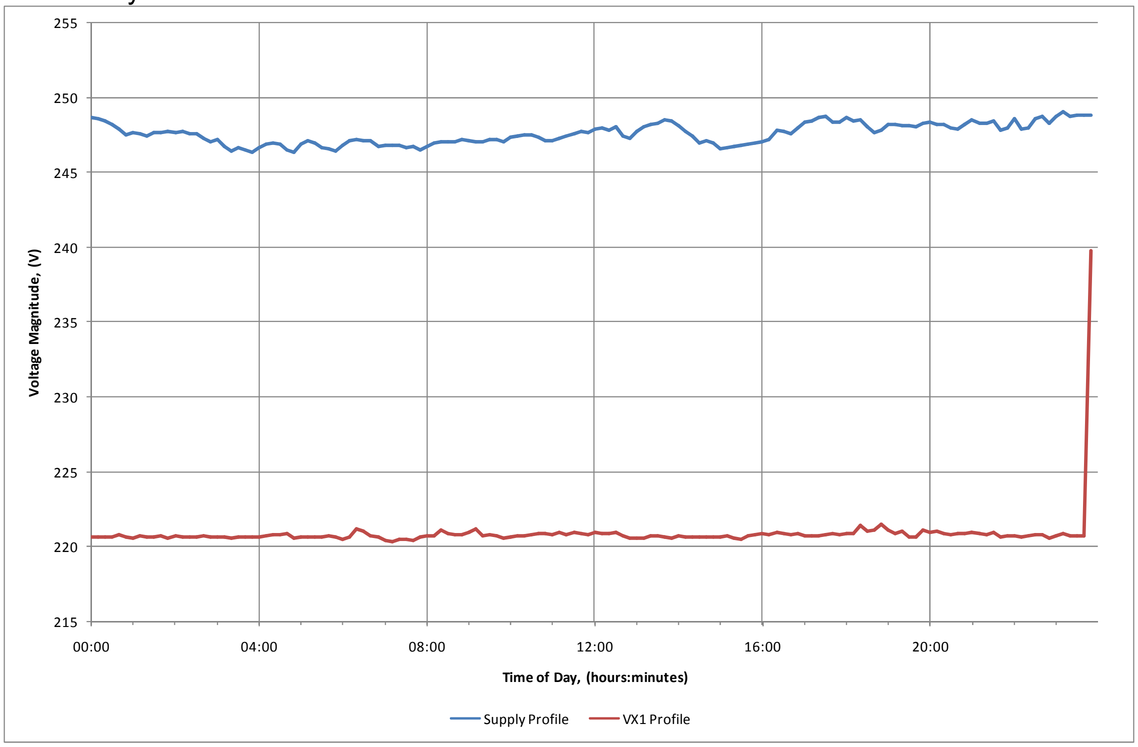


Figure 15: Site 60 Daily Voltage Profiles
"Supply Profile" – mean for ON and OFF days
"VX1 Profile" – mean for ON days (can show effects at the ends due to switching ON/OFF of the VX1)

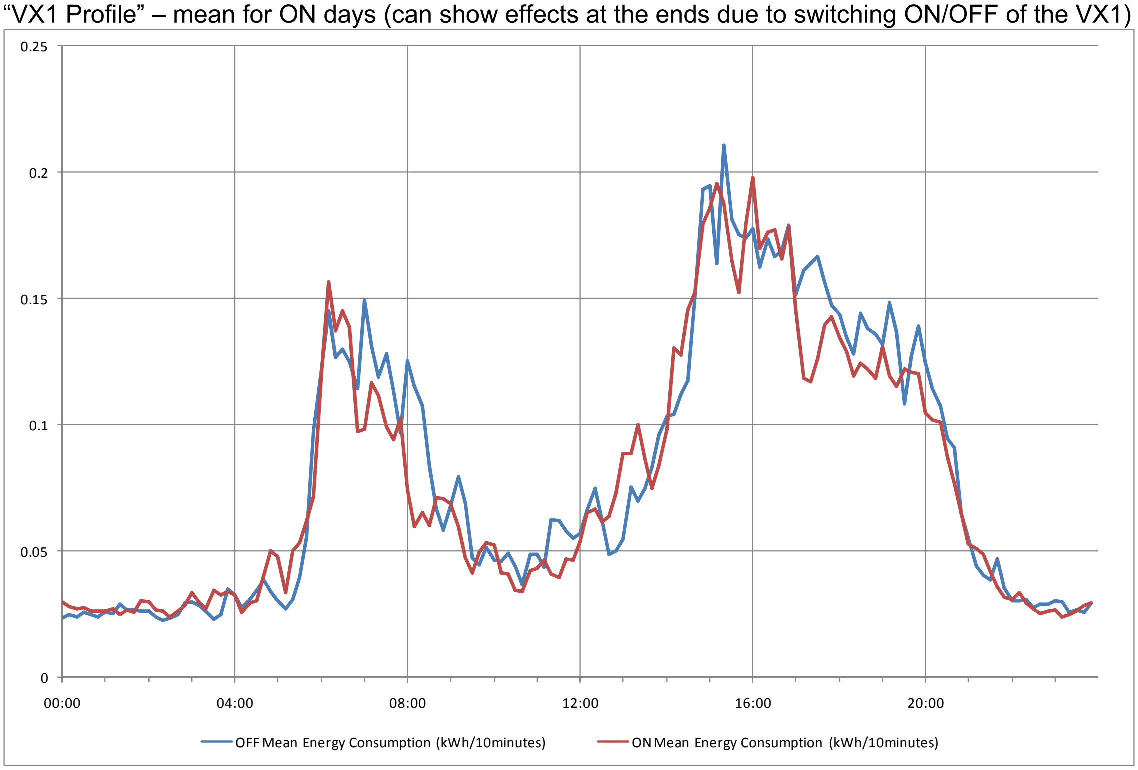


Figure 16: Site 60 Daily ON and OFF Demand Profiles

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

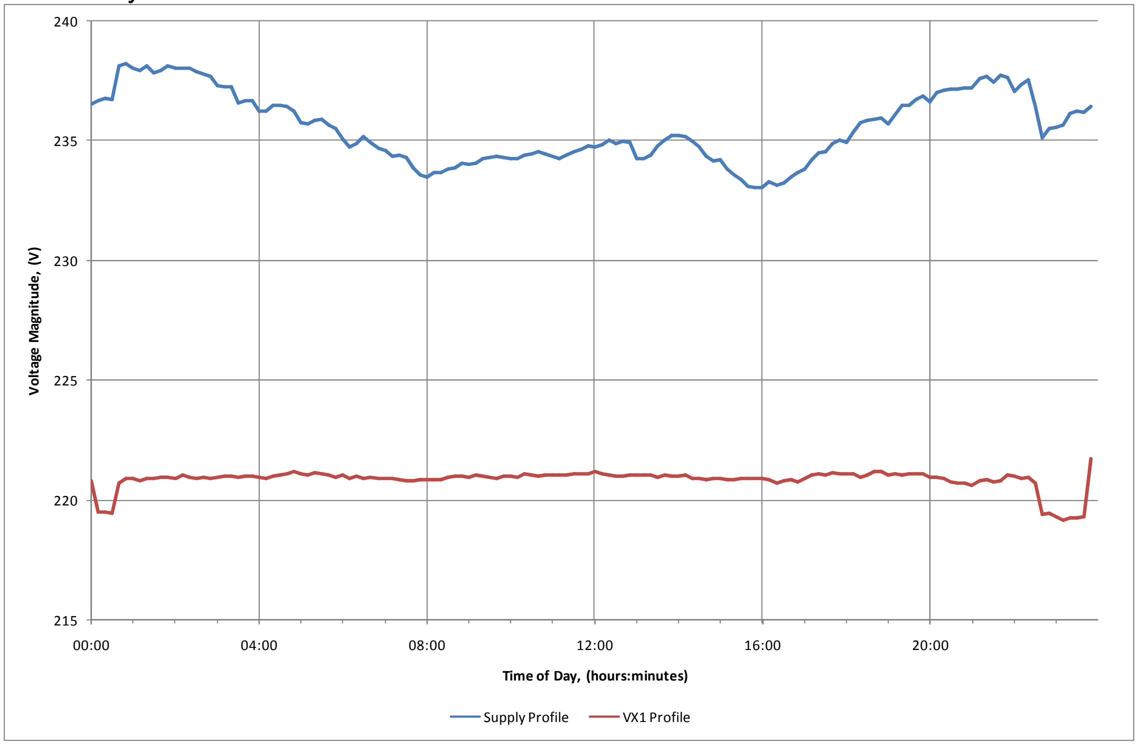


Figure 17: Site 65 Daily Voltage Profiles

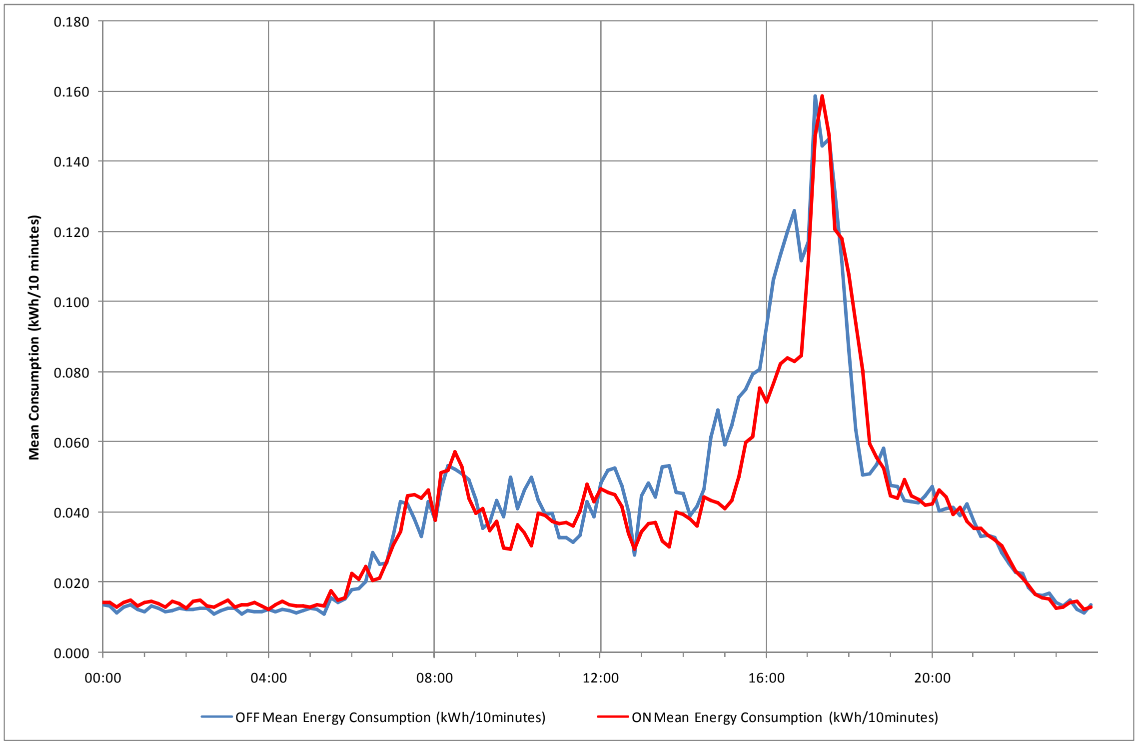


Figure 18: Site 65 Daily ON and OFF Demand Profiles

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

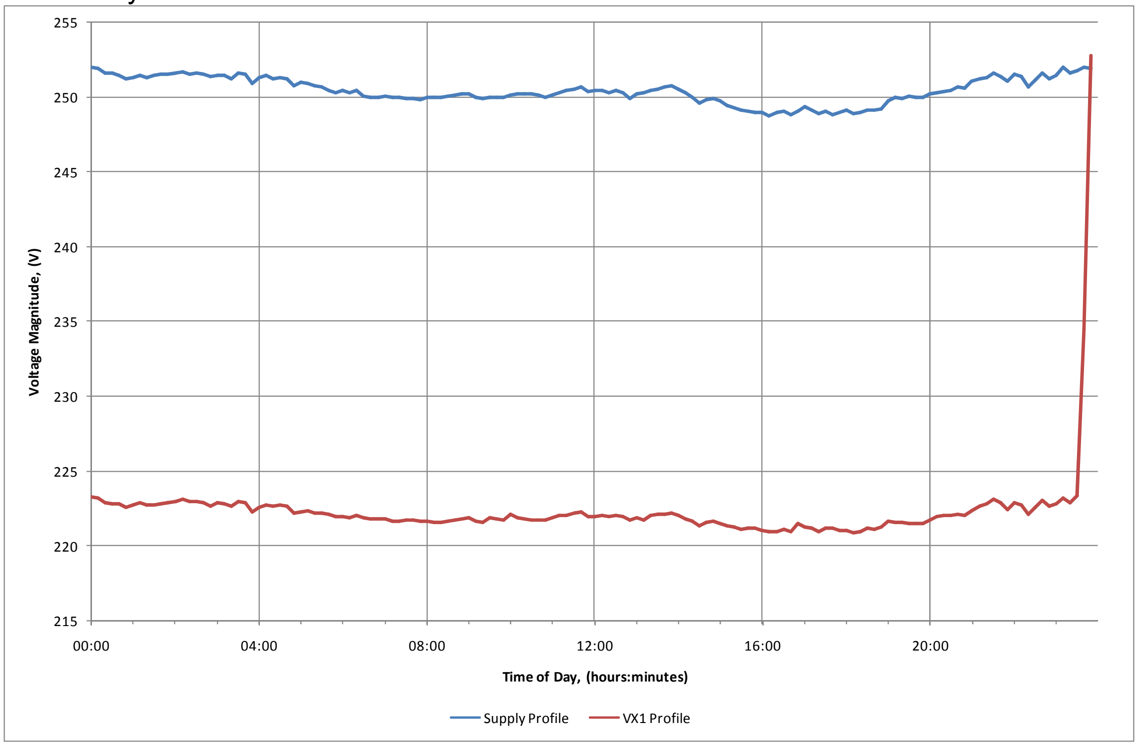


Figure 19: Site 37 Daily Voltage Profiles

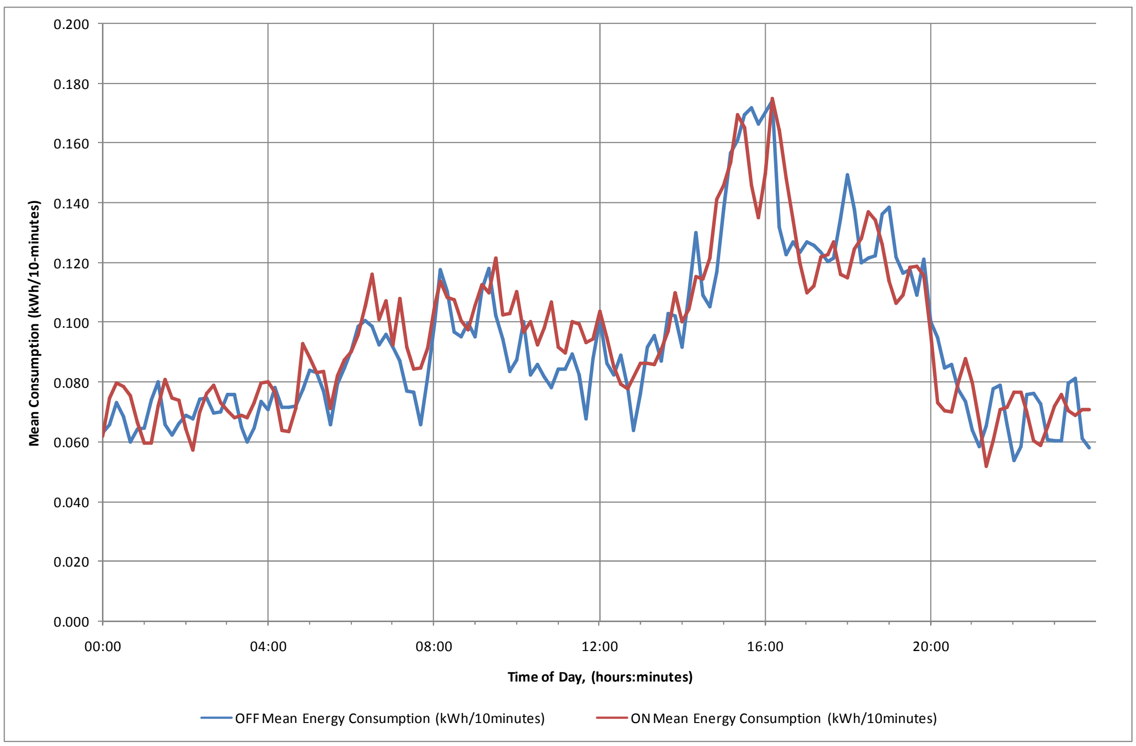


Figure 20: Site 37 Daily ON and OFF Demand Profiles

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_2 Abatement by Property type

	Mean $kgCO_2$/year	Confidence $\pm kgCO_2$/year
Flat	44	49
Maisonnette	75	-
Bungalow	-	-
Terraced	108	48
Semi	146	86
Detached	138	89

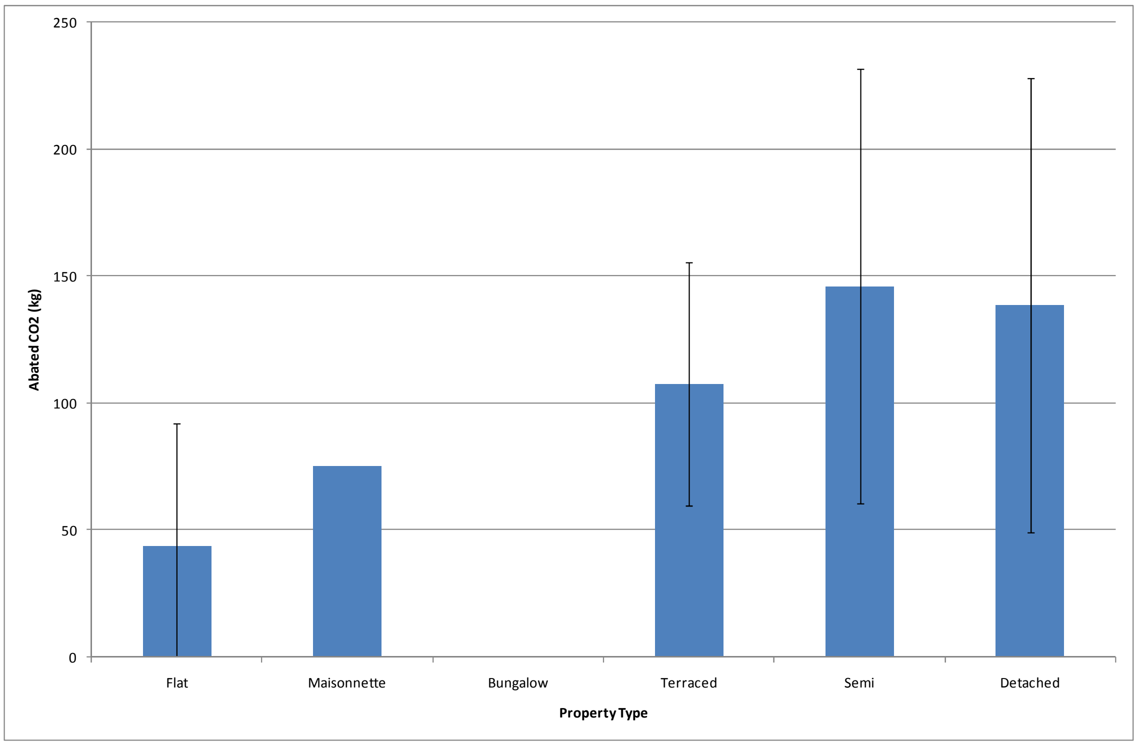


Figure 21: Abated Carbon by Property Type

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

CHANGE RECORD

ISSUE	DATE	SECTION AFFECTED	REASON OF CHANGE/REMARKS
01	4/13/2009	All	Initial Release
02	6/2/2010	Section 7	Changed example from 30C to 50C.

	COMPANY / DEPT	NAME	DATE	SIGNATURE
Prepared By:	Relex Software Corp.	J. Marzina	6/2/2010	
Checked by:	Relex Software Corp.	K. Mohan	6/2/2010	
Released by:	Relex Software Corp.	K. Stillwell	6/2/2010	

DISTRIBUTION LIST

To: A. Smithies

Cc: J. Marzina, K. Mohan, K. Stillwell, C. Swallow

EXECUTIVE SUMMARY

A reliability prediction was performed using Telcordia Issue 2 on the VX1 designed and developed by Energetix Group. The failure rate of the VX1 was calculated to be 2218.709835 FITs (failures per billion hours) yielding a MTBF of 450,712 hours or 51 years. The calculation was performed using a Ground Fixed, Uncontrolled environment and the Parts Stress method in Telcordia Reliability Prediction Procedure for Electronic Equipment (SR-332), Issue 2. A 60% upper confidence level was used for this analysis.

TABLE of CONTENTS

1. INTRODUCTION

This report contains the Telcordia reliability prediction for the VX1 designed and developed by Energetix Group. The analysis has been conducted in accordance with the Telcordia Reliability Prediction Procedure for Electronic Equipment (SR-332), Issue 2, using the Parts Stress calculation method (Method 1 Case 3).

1.1 Purpose

The purpose of this report is to determine the failure rate and MTBF for the VX1. Energetix Group may use the assessment in the elimination of potential reliability problems.

1.2 Summary

The failure rate of the VX1 was predicted to be 2218.709835 FITs yielding a MTBF of 450,712 hours or 51 years. The calculation was performed using 21°C ambient temperature, a temperature rise of 20°C on all parts, the Ground Fixed, and Parts Stress method in Telcordia Reliability Prediction Procedure for Electronic Equipment (SR-332), Issue 2.

1.3 Design Status

This document reflects the current design concept/configuration that is outlined in the documentation supplied by Energetix Group. The documentation is considered to be representative of the final equipment design.

2. APPLICABLE DOCUMENTS

The following documents were used as a basis for this report.

2.1 Company Documents

Document	Type	Date
0736PartsListwithManufacturersDetails (3).xlsx	Bill of Materials	11/05/2008
20081121 VX1 component stress.xls	Stress Data	11/24/2008

2.2 General References

Document	Type	Date
Telcordia SR-332 Issue 2	Reliability Prediction Procedure for Electronic Equipment	September 2006
NPRD-95, Non-Electronic Parts Reliability Data	Published by the Reliability, Analysis Center (RAC)	1995

3. ACRONYMS, ABBREVIATIONS AND DEFINITIONS

3.1 Acronyms and Abbreviations

BOM	Bill of Materials
FITs	Failures in Time (Failures Per Billion Hours)
GF, GU	Ground Fixed, Uncontrolled
MTBF	Mean Time Between Failures

3.2 Definitions

Failure The events, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.

Failure Rate The total number of failures within an item population, divided by the total number of life units expended by that population, during a particular measurement interval under stated conditions.

MTBF The average value of the times between successive outages of the system.

Reliability The ability of an item to perform a required function under specified conditions for a specified period of time.

4. SYSTEM REQUIREMENTS

4.1 Reliability Requirements

It has been assumed that there are no known quantitative reliability requirements or reliability demonstration test requirements for the elements of the VX1 provided by Energetix Group.

Primary emphasis shall be on component failure rate data. Techniques shall be used which have proven successful in achieving reliable equipment design, for example, components shall be operated within their specified ratings and environments with adequate margins. Parts standardization, type and quantity minimization, and credible single point failure (SPF) minimization shall be evaluated in the design.

5. ANALYTICAL APPROACH

5.1 Reliability Mathematics

The reliability prediction documented in this report was performed in accordance with the “Parts Stress” method using the Relex Reliability Studio 2008. This was completed utilizing the part failure rate data models and relevant quality, environmental factors as specified in the Telcordia SR332 Issue 2, Parts Stress methodology.

At the time this report was generated we assumed that the VX1 was operating within the following conditions

Parameter	Value
Environment	GF, GU - Ground Fixed, Uncontrolled
Operating Ambient Temperature	21°C
Temperature Rise	20°C For all parts

5.2 Parts Quality

The quality of a component used in the electronic design has a direct effect on the part failure rate and appears in the part models as a factor PiQ. The quality level included in the part failure rate models for this analysis is

Part/Category	Quality Level
TXR-0736P01A, BE1990, FUS 5.0A – 20 MM – GQB, TXR-AC1025/25A, RLY-0736P13A	Level III
FETs, Diodes, Transistors	Level II
Capacitors, Resistors, all remaining components	Level I

The definition of these quality levels are listed in the Telcordia standard as:

5.2.1 Quality Level I definition

"This level shall be assigned to commercial-grade components that are procured and used without thorough device qualification or lot-to-lot controls by the equipment manufacturer. However **(a)** steps must have been taken to ensure that the components are compatible with the design application and manufacturing process; and **(b)** an effective feedback and corrective action program must be in place to identify and resolve problems quickly in manufacture and in the field".

5.2.2 Quality Level II definition

"This level shall be assigned to components that meet requirements **(a)** and **(b)** of Quality Level I (see definition below), plus the following: **(c)** purchase specifications must explicitly identify important characteristics (electrical, mechanical, thermal, and environmental) and acceptable quality levels (i.e., AQLs, DPMs, etc.) for lot control; **(d)** devices and device manufacturers must be qualified and identified on approved parts/manufacturer's lists (device qualification must include appropriate life and endurance tests); **(e)** lot-to-lot controls, either by the equipment manufacturer or the device manufacturer, must be in place at adequate AQLs/DPMs to ensure consistent quality.

5.2.3 Quality Level III definition

This level shall be assigned to components that meet requirements **(a)** through **(e)** of Quality Levels I and II, plus the following: **(f)** device families must be requalified periodically; **(g)** lot-to-lot controls must include early life reliability control of 100% screening (temperature cycling and burn-in), which, *if the results warrant it,* may be reduced to a "reliability audit" (i.e., a sample basis) or to an acceptable "reliability monitor" with demonstrated and accepted cumulative early failure values of less than 200 ppm out to 10,000 hours; **(h)** where burn-in screening is used, the Percent Defective Allowed (PDA) shall be specified and shall not exceed 2%; and **(i)** an ongoing, continuous reliability improvement program must be implemented by both the device and equipment manufacturers.

5.3 Duty Cycle

All components were assumed to be in continuous operation with a duty cycle of 100%.

5.4 Component Stress

Component stress is another factor that is used in the failure rate calculation using Telcordia. For example: A 1/2W resistor is assumed to be operating at no more than 1/4W. This means that a component stress of 50% is taken into account in the failure rate calculation for the resistor.

The following table shows the stress ratio that is used in the calculation for each part type as required by Telcordia Issue 2.

Component Type	Stress Ratio Type
Capacitor	Voltage
Resistor	Power
Relay, Switch	Current
Diode, general	Current and Voltage

Component Type	Stress Ratio Type
Diode, zener	Power
Varactor, Step-recovery, Tunnel diode	Actual dissipated power / rated power
SiFET	Power
Transistor	Power, Voltage

Energetix provided the operating parameters (voltage, current, or power) for many of the parts. Relex found the rated parameters on the datasheets. For parts without an operating parameter from Energetix, the default of 50% was used for the stress ratio. Section 8.1 of this report lists the stress ratio that was used for each part in the analysis.

5.5 Confidence Level

For this analysis, the upper confidence level was set to 60%. This means that there is a 60% confidence that the actual failure rate will be less than the calculated failure rate. In Telcordia Issue 2, the confidence level is an input that must be specified between 0% and 100%. The higher the confidence level that is chosen, the higher the failure rate will be because it is a more conservative prediction.

5.6 General Assumptions

(1) The operating temperatures fall within the equipment's rated range.

(2) The design incorporates performance margins, which are adequate to withstand the worst-case impacts of parameter variation. These variations may be due to initial production and/or component tolerances, input power/signal or load variations. Those variations may be due to the effects of aging and exposure to adverse thermal environments for the duration of planned operations.

(3) An adequate cooling path is provided for the equipment in order to eliminate overheating.

(4) The equipment's useful life commences after screening, assembly, and burn-in have been completed.

(5) The production (including assembly, integration, and testing), handling, transportation and storage are conducted under approved conditions. The production will not introduce unknown latent damage or failure mechanisms, which would result in the degradation of the equipment's expected reliability or useful life.

(6) The equipment is operating continuously.

(7) Printed circuit boards are assumed to have a failure rate of 0.

(8) Optional components that are not installed are assumed to have a failure rate of 0.

(9) Mechanical components are assumed to have a failure rate of 0.

(10) If there are LEDs within a connector, they are excluded from the prediction because they do not have a direct impact on the function or maintenance of the connector.

6. METHODS FOR IMPROVING RELIABILITY

The reliability prediction analysis allows the engineering team to quantitatively measure the initial system reliability and the effectiveness of any subsequent reliability improvement steps. The reliability can be improved by implementing the following considerations during the design process:

(1) **Reduce Component Count:** Preference should be directed towards the use of innovative design ideas, and more highly integrated functional parts while attempting to reduce the total number of parts without adversely effecting circuit performance. A reduction in the number of parts can also lead to lower cost and less required board space

(2) **Part Selection:** The quality and reliability of the components used in the design directly impacts a product's reliability. Preference should be given to those suppliers that produce high quality parts with a proven reliability.

(3) **Derating:** Failure rate of components generally decreases with decrease in applied stress levels. Therefore, derating, or operating the part at levels below its specified ratings (for current, voltage, power dissipation, temperature, etc.) can increase the part reliability. Parts derating can be achieved by circuit design (minimize applied stress), part selection (use parts with ratings well above given applied stress), and thermal design (reduce part operating temperature).

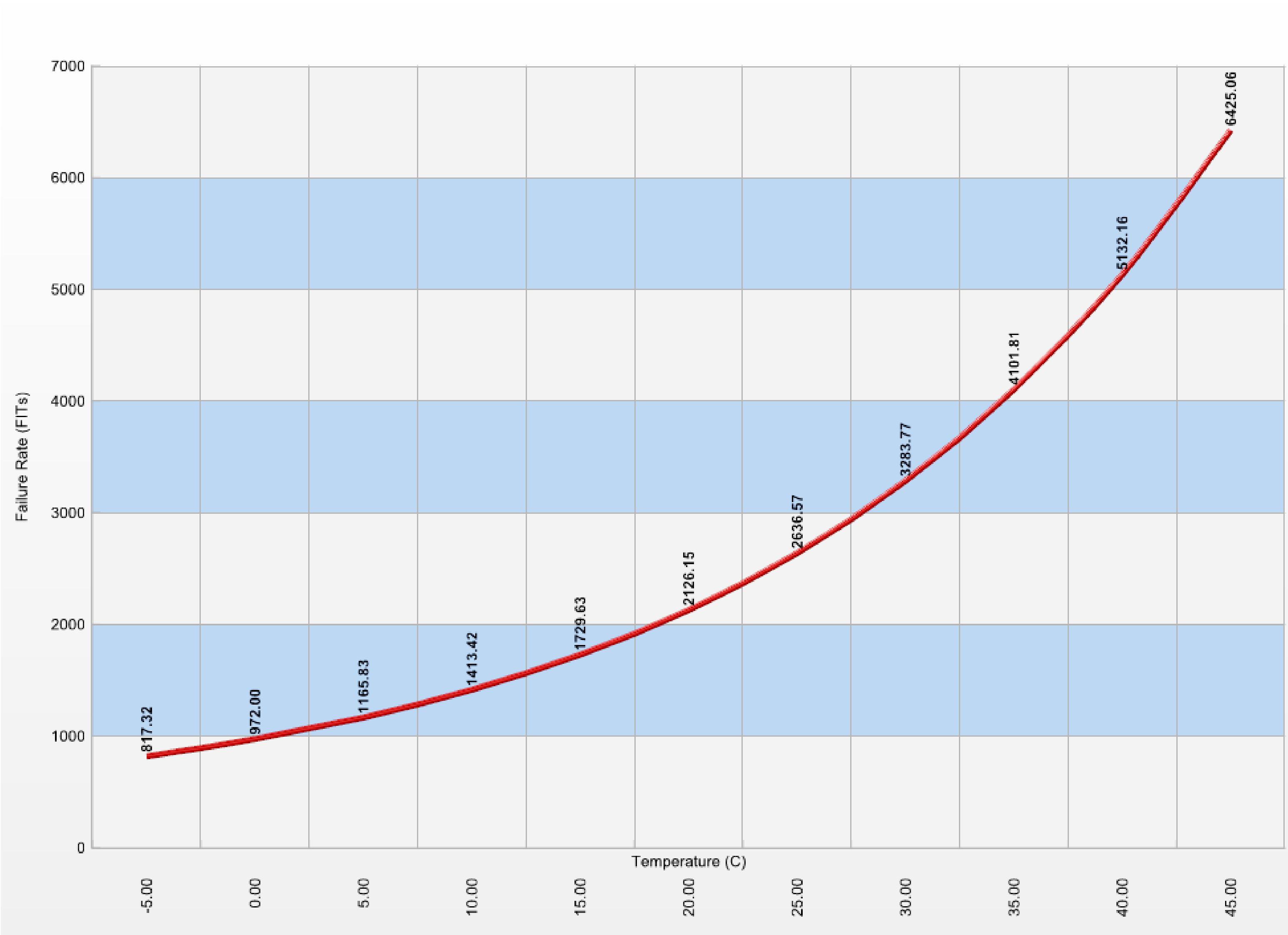
(4) **Burn-In:** Burn-in is operation in the manufacturer's factory, at an elevated temperature, to accelerate the rate of infant mortality failures. Burn-in allows the design team to weed out failure prone devices in the factory, rather than in the field. Note that burn-in can be performed at the component, board, or system level.

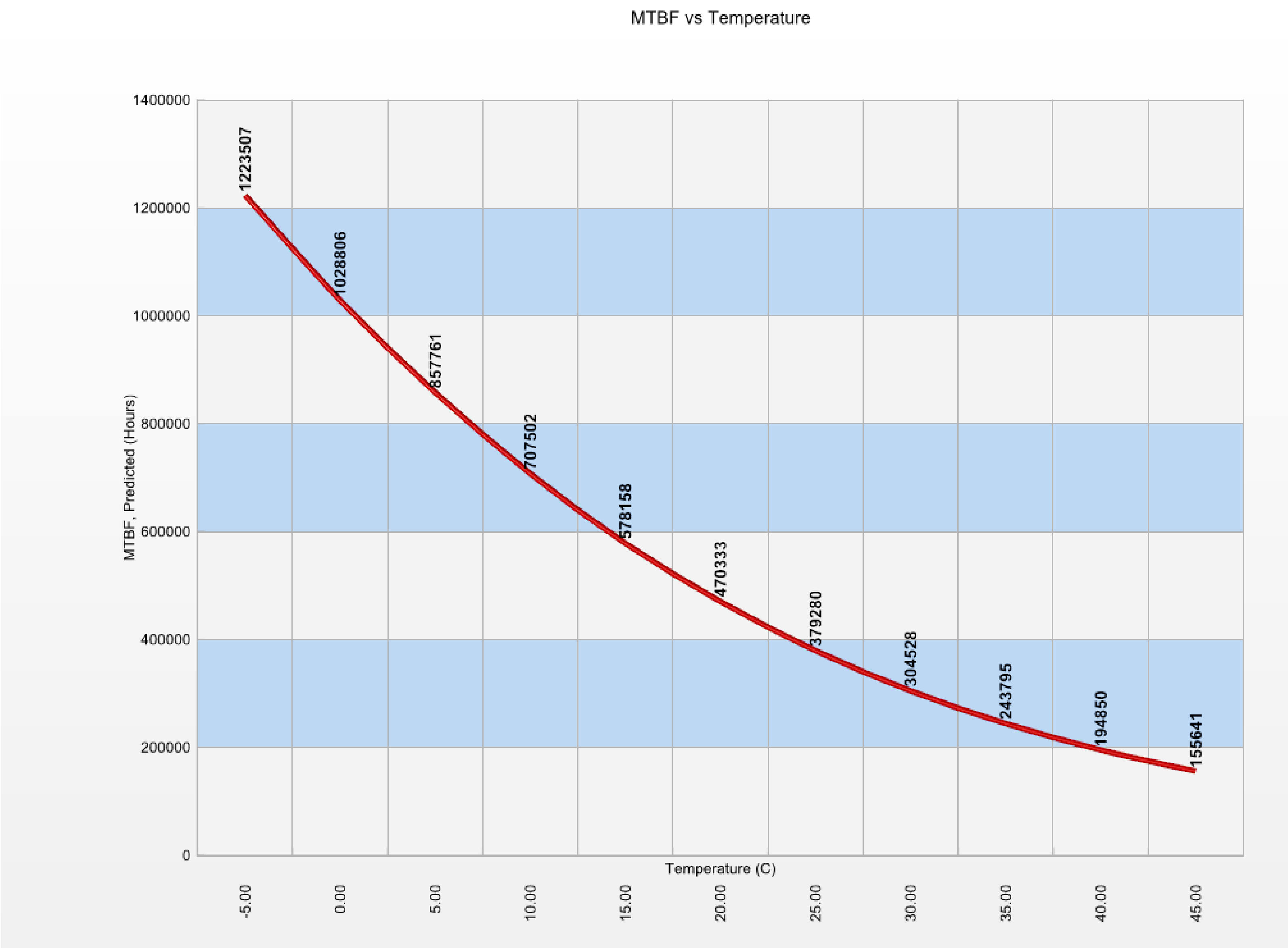
(5) **Redundancy:** A product's reliability may be greatly enhanced by using redundant design techniques.

7. RELIABILITY GRAPHS

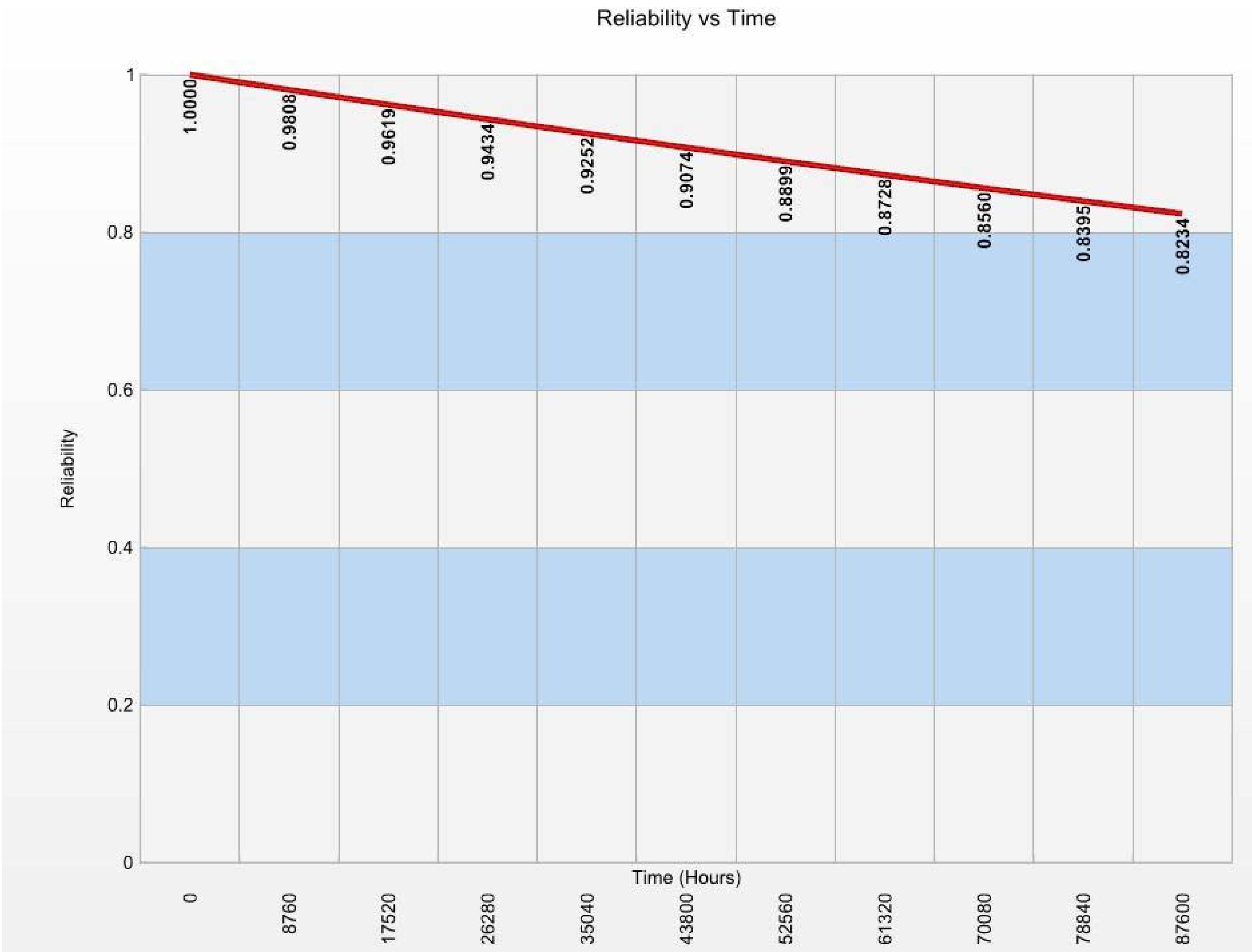
The temperatures given in the x-axes of the first two graphs represent the temperature inside the VX1's enclosure. For example, 50°C shown on the graph means that the temperature outside of the VX1's enclosure is 30°C and the ambient temperature inside the enclosure is 50°C.

Failure Rate vs. Temperature





MTBF vs Temperature
MTBF, Predicted (Hours)
1400000
1200000
1000000
800000
600000
400000
200000
0
Temperature (C)
-5.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
1223507
1028806
857761
707502
578158
470333
379280
304528
243795
194850
155641


Reliability vs Time
Reliability
Time (Hours)
1
0.8
0.6
0.4
0.2
0
1.0000
0.9808
0.9619
0.9434
0.9252
0.9074
0.8899
0.8728
0.8560
0.8395
0.8234
0
8760
17520
26280
35040
43800
52560
61320
70080
78840
87600

8. RELIABILITY WORK SHEETS

8.1 Prediction Report

Reliability Prediction Report

Assembly VX1 **Model** Telcordia Issue 2 **Failure Rate** 2218.709835 FIT(s)
Description Smart Voltage **Temperature** 21.00 C **MTBF** 450712 hours
Date 3/26/2009 8:54:34 AM **Environment** GF, GU - Ground Fixed, Uncontrolled **Confidence** 60 %

Assy. Name	Description	Quantity	Total Failure Rate (FITs)	Reliability (at 1 year)	MTBF (hours)
VX1	Smart Voltage Management Device	1	2218.7	0.980752	450712
SUB-0736PCB/A	ROHS SUB ASSY 0736 VOLTAGE REGULATOR	1	2198.3	0.980927	454895

File Name Energetix R-0264

Reliability Prediction Report

Assembly VX1 **Model** Telcordia Issue 2 **Failure Rate** 2218.709835 FITs
Description Smart Voltage **Temperature** 21.00 C **MTBF** 450712 hours
Date 3/26/2009 8:54:38 **Environment** GF, GU - Ground Fixed, **Confidence** 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
TXR-0736P05A		BE1990	Inductor				20	1	18.784196	53236241.45
FUS-0736P02A		TBC	Miscellaneous				20	1	2.509733	398448751.27

Reliability Prediction Report

Assembly	SUB-0736PCB/A	**Model**	Telcordia Issue 2	**Failure Rate**	2198.309822	FITs
Description	ROHS SUB ASSY	**Temperature**	21.00 C	**MTBF**	454895	hours
Date	3/26/2009 8:54:38	**Environment**	GF, GU - Ground Fixed,	**Confidence**	60 %	

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
FSH20MM-CFH14	F4	646019	Fuse Holder				20	1	127.900000	7818608.29
ICT-XC2C64A-VQ44	IC11	XC2C64A-7VQG44I	Integrated Circuit				20	1	124.650736	8022415.56
E-470/35/ELOZ	C44	RP1V477M10020PA200	Capacitor	57			20	1	108.960184	9177664.39
ICT-LM809M3-3.08	IC1	LM809M3-3.08/NOPB	Integrated Circuit				20	1	93.871549	10652855.01
ICT-7805/TO252	IC5	MC78MO5BDTRKG	Integrated Circuit				20	1	93.871549	10652855.01
ICT-NCP502SN30	IC3	NCP502SN30T1G	Integrated Circuit				20	1	93.871549	10652855.01
ICT-LM2901D	IC6	LM2901DR2G	Integrated Circuit				20	1	93.871549	10652855.01
ICT-LM4128BMF3.3	IC4	LM4128BMF-3.3/NOPB	Integrated Circuit				20	1	93.871549	10652855.01
ICT-L7812CD2T-TR	IC18	L7812CD2T-TR	Integrated Circuit				20	1	93.871549	10652855.01
ICT-FAN2558S18X	IC2	FAN2558S18X	Integrated Circuit				20	1	93.871549	10652855.01
E-1000/25/EL	C50	RP1E108M12020CA	Capacitor	48			20	1	88.004023	11363116.87
E-1000/25/EL	C45	RP1E108M12020CA	Capacitor	48			20	1	88.004023	11363116.87
E-1000/25/EL	C46	RP1E108M12020CA	Capacitor	48			20	1	88.004023	11363116.87
E-1000/25/EL	C47	RP1E108M12020CA	Capacitor	48			20	1	88.004023	11363116.87
ICT-ST7FLT35F2M6	IC16	ST7FLITE35F2M6	Integrated Circuit				20	1	83.811412	11931549.44
ICT-74HC74/SM	IC8	SN74ACT74D	Integrated Circuit				20	1	27.432817	36452690.65
ICT-74HC04/SM	IC7	MC74HC04ADR2	Integrated Circuit				20	1	25.703352	38905431.91
TXR-0736P01A	TX2	TXR-0736P01A	Inductor				20	1	18.784196	53236241.45
TXR-AC1025/25A	TX1	AC1025	Inductor				20	1	18.784196	53236241.45
COI-3.9MH/2.8A	L3	1140-392K-RC	Inductor				20	1	14.709769	67982035.05
PLG-MOLEX7X2/2MM	CN1	878311420	Connection				20	1	11.651391	85826663.54
COI-B82734-R2322	L4	B82734-R2322-B30	Inductor				20	1	10.885184	91867992.21
RLY-DPCO/12V/8A	RL1	G2RL2-12VDC	Relay				20	1	10.632309	94052950.00
VDR-265VRMS	R84	VDRS07H275TSE	Semiconductor				20	1	10.500947	95229509.04
VDR-265VRMS	R138	VDRS07H275TSE	Semiconductor				20	1	10.500947	95229509.04
TRS-FCB20N60F	T20	FCB20N60F	Semiconductor				20	1	10.068093	99323675.77
TRS-FCB20N60F	T19	FCB20N60F	Semiconductor				20	1	10.068093	99323675.77
TRS-FCB20N60F	T18	FCB20N60F	Semiconductor				20	1	10.068093	99323675.77
TRS-FCB20N60F	T17	FCB20N60F	Semiconductor				20	1	10.068093	99323675.77
DIO-B6S	D27	B6S	Semiconductor	60	33		20	1	9.507475	105180394.06
PLG-IDC10/0.1	CN5	302-S-10-D1-R1	Connection				20	1	8.322422	120157328.96
C150N-275/X2/10	C56	2222-338-20154	Capacitor	57			20	1	7.305150	136889723.00

Relex

Reliability Prediction Report

Assembly	SUB-0736PCB/A	**Model**	Telcordia Issue 2	**Failure Rate**	2198.309822 FITs
Description	ROHS SUB ASSY	**Temperature**	21.00 C	**MTBF**	454895 hours
Date	3/26/2009 8:54:38	**Environment**	GF, GU - Ground Fixed,	**Confidence**	60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
C2N2-250/Y2/20	C52	336663222	Capacitor	57			20	1	7.305150	136889723.00
C1U-630/MPP/10	C55	MKP1840-510/635-2M	Capacitor	57			20	1	7.305150	136889723.00
C2N2-250/Y2/20	C54	336663222	Capacitor	57			20	1	7.305150	136889723.00
C1U-630/MPP/10	C43	MKP1840-510/635-2M	Capacitor	57			20	1	7.305150	136889723.00
DIO-BAT54/S	D8	BAT54SLT1G	Semiconductor				20	1	7.300415	136978515.90
DIO-BAT54/S	D9	BAT54SLT1G	Semiconductor				20	1	7.300415	136978515.90
DIO-BAV99	D18	BAV99E6327-BOX	Semiconductor				20	1	7.300415	136978515.90
DIO-BAT54/S	D17	BAT54SLT1G	Semiconductor				20	1	7.300415	136978515.90
DIO-BAT54/S	D4	BAT54SLT1G	Semiconductor				20	1	7.300415	136978515.90
DIO-BAT54/C	D2	BAT54C	Semiconductor				20	1	7.300415	136978515.90
ZDO4V7-BZV55C	Z1	TZMC4V7GS08-BOX	Semiconductor				20	1	7.257695	137784801.49
ZDO4V7-BZV55C	Z3	TZMC4V7GS08-BOX	Semiconductor				20	1	7.257695	137784801.49
ZDO15V-BZV55C	Z4	BZV55-C15/T1	Semiconductor				20	1	7.257695	137784801.49
ZDO15V-BZV55C	Z5	BZV55-C15/T1	Semiconductor				20	1	7.257695	137784801.49
TRM-1-794065-0	CN4	1-794065-0	Connection				20	1	6.657938	150196661.20
RLY-0736P13A	RL3	HFE11-3/12-HT(249)	Relay				20	1	6.563242	152363716.97
IND-2M2H/PK0810	L1	PK0810-222	Inductor				20	1	6.296809	158810593.99
IND-2M2H/PK0810	L2	PK0810-222	Inductor				20	1	6.296809	158810593.99
VDR-265VRMS	R129	VDRS07H275TSE	Semiconductor		4		20	1	5.789613	172723122.19
ICT-HCPL3180/SM	IC12	HCPL-3180-500E	Optical Device				20	1	4.782382	209100816.53
ICT-HCPL3180/SM	IC14	HCPL-3180-500E	Optical Device				20	1	4.782382	209100816.53
ICT-HCPL3180/SM	IC13	HCPL-3180-500E	Optical Device				20	1	4.782382	209100816.53
ICT-HCPL3180/SM	IC15	HCPL-3180-500E	Optical Device				20	1	4.782382	209100816.53
DIO-B6S	D26	B6S	Semiconductor	60	7		20	1	4.395927	227483319.48
DIO-B6S	D29	B6S	Semiconductor	60	7		20	1	4.395927	227483319.48
TRS-BC847	T2	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BCX56	T22	BCX56/T3	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T1	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T3	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T5	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BCX53	T16	BCX53/T1	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T14	BC847	Semiconductor				20	1	3.654729	273618112.26

Reliability Prediction Report

Assembly SUB-0736PCB/A **Model** Telcordia Issue 2 **Failure Rate** 2198.309822 FITs

Description ROHS SUB ASSY **Temperature** 21.00 C **MTBF** 454895 hours

Date 3/26/2009 8:54:38 **Environment** GF, GU - Ground Fixed, **Confidence** 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
TRS-BCX53	T15	BCX53/T1	Semiconductor				20	1	3.654729	273618112.26
TRS-BCX56	T21	BCX56/T3	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T8	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T6	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T7	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T9	BC847	Semiconductor				20	1	3.654729	273618112.26
TRS-BC847	T4	BC847	Semiconductor				20	1	3.654729	273618112.26
RES1K-RC02H	R110	1K-RC02H-DRM	Resistor			42	20	1	2.952655	338678245.94
RES1K-RC02H	R112	1K-RC02H-DRM	Resistor			39	20	1	2.832344	353064418.74
RES27R-RC12H	R106	RC0805FR-0727RL	Resistor			30	20	1	2.513069	397919820.77
RES27R-RC12H	R105	RC0805FR-0727RL	Resistor			30	20	1	2.513069	397919820.77
RES27R-RC12H	R104	RC0805FR-0727RL	Resistor			30	20	1	2.513069	397919820.77
RES27R-RC12H	R103	RC0805FR-0727RL	Resistor			30	20	1	2.513069	397919820.77
FUS-1A/SMD	F3	R452 001	Miscellaneous				20	1	2.509733	398448751.27
FUS-1A/SMD	F1	R452 001	Miscellaneous				20	1	2.509733	398448751.27
FUS-1A/SMD	F2	R452 001	Miscellaneous				20	1	2.509733	398448751.27
RES220K-RC12H	R120	RC0805FR-10220KL	Resistor			25	20	1	2.367193	422441311.58
RES220K-1206/0.1	R136	239061142204	Resistor			25	20	1	2.367193	422441311.58
RES220K-1206/0.1	R135	239061142204	Resistor			25	20	1	2.367193	422441311.58
RES220K-1206/0.1	R134	239061142204	Resistor			25	20	1	2.367193	422441311.58
RES220K-RC12H	R113	RC0805FR-10220KL	Resistor			25	20	1	2.367193	422441311.58
RES1K-RC22H	R79	RT0603FR-071KL	Resistor			25	20	1	2.354915	424643727.72
RES220K-1206/0.1	R124	239061142204	Resistor			24	20	1	2.327523	429641237.76
RES220K-1206/0.1	R125	239061142204	Resistor			24	20	1	2.327523	429641237.76
RES220K-1206/0.1	R123	239061142204	Resistor			24	20	1	2.327523	429641237.76
RES2K2-RC02H	R128	RC02H-2K2-DRM	Resistor			20	20	1	2.198125	454933170.27
RES2K2-RC02H	R109	RC02H-2K2-DRM	Resistor			20	20	1	2.198125	454933170.27
RES10R-RC02H	R68	RC1206FR-1010RL	Resistor			20	20	1	2.195269	455524967.98
DIO-0724P06A	D1	0724P06A	Semiconductor					1	2.099830	476229120.43
DIO-0724P06A	D7	0724P06A	Semiconductor					1	2.099830	476229120.43
RES150R-RC22H	R100	232270461501	Resistor			15	20	1	2.067840	483596329.93
RES150R-RC22H	R19	232270461501	Resistor			15	20	1	2.067840	483596329.93

Reliability Prediction Report

Assembly SUB-0736PCB/A **Model** Telcordia Issue 2 **Failure Rate** 2198.309822 FITs
Description ROHS SUB ASSY **Temperature** 21.00 C **MTBF** 454895 hours
Date 3/26/2009 8:54:38 **Environment** GF, GU - Ground Fixed, **Confidence** 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
RES150R-RC22H	R5	232270461501	Resistor			15	20	1	2.067840	483596329.93
RES150R-RC22H	R98	232270461501	Resistor			15	20	1	2.067840	483596329.93
LEDGRN-2SYGD/E2	LED2	333-2SYGD/S530-E2/TR1-2	Optical Device				20	1	2.014190	496477499.10
LEDRED-2SURD/A3	LED1	333-2SURD/S530-A3/TR1-2	Optical Device				20	1	2.014190	496477499.10
RES1K-RC22H	R69	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R64	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R63	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R62	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R60	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R27	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R54	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R29	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R32	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R31	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R72	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R74	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R80	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K-RC22H	R43	RT0603FR-071KL	Resistor			11	20	1	1.960510	510071304.99
RES1K2-RC22H	R22	RC0603FR-071K2L	Resistor			9	20	1	1.915167	522147716.50
C1U-25/1206/10	C40	GRM42-6X7R105K25	Capacitor	60			20	1	1.886559	530065542.89
C1U-25/1206/10	C38	GRM42-6X7R105K25	Capacitor	60			20	1	1.886559	530065542.89
RES10K-RC22H	R82	2322 704 71003	Resistor			5	20	1	1.813402	551449645.36
RES10K-RC22H	R91	2322 704 71003	Resistor			5	20	1	1.813402	551449645.36
RES3K3-RC22H	R97	RC0603FR-073K3L	Resistor			3	20	1	1.776073	563039918.96
RES3K3-RC22H	R6	RC0603FR-073K3L	Resistor			3	20	1	1.776073	563039918.96
RES3K3-RC22H	R7	RC0603FR-073K3L	Resistor			3	20	1	1.776073	563039918.96
RES3K3-RC22H	R99	RC0603FR-073K3L	Resistor			3	20	1	1.776073	563039918.96
RES10K-RC22H	R70	2322 704 71003	Resistor			3	20	1	1.757698	568926089.15
RES10K-RC22H	R139	2322 704 71003	Resistor			3	20	1	1.757698	568926089.15
RES10K-RC22H	R140	2322 704 71003	Resistor			3	20	1	1.757698	568926089.15
RES4K7-RC22H	R13	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R14	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62

Reliability Prediction Report

Assembly SUB-0736PCB/A
Description ROHS SUB ASSY
Date 3/26/2009 8:54:38

Model Telcordia Issue 2
Temperature 21.00 C
Environment GF, GU - Ground Fixed,

Failure Rate 2198.309822 FITs
MTBF 454895 hours
Confidence 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
RES4K7-RC22H	R15	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R16	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R94	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R4	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R1	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R33	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R17	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R9	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R95	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R144	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R117	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R108	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R55	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R92	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R93	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES4K7-RC22H	R83	RC0603FR-134K7L	Resistor			2	20	1	1.753133	570407221.62
RES100R-0.5W/SM	R122	MCR50-JZH-F-100R	Resistor			2	20	1	1.746310	572636153.38
RES100R-0.5W/SM	R121	MCR50-JZH-F-100R	Resistor			2	20	1	1.746310	572636153.38
RES3K3-RC22H	R107	RC0603FR-073K3L	Resistor			2	20	1	1.746310	572636153.38
RES3K3-RC22H	R96	RC0603FR-073K3L	Resistor			2	20	1	1.746310	572636153.38
RES12K-0603/0.1	R11	RT0603BRE0712KL	Resistor			2	20	1	1.746310	572636153.38
RES1K-RC22H	R48	RT0603FR-071KL	Resistor			2	20	1	1.746310	572636153.38
RES56K-RC22H	R88	CRG 0603 1% 56K	Resistor			2	20	1	1.744041	573381064.46
RES12K-0603/0.1	R137	RT0603BRE0712KL	Resistor			2	20	1	1.739512	574873794.94
RES100K-RC22H	R101	CRG 0603 1% 100K	Resistor			1	20	1	1.730490	577870924.46
RES100K-RC22H	R102	CRG 0603 1% 100K	Resistor			1	20	1	1.730490	577870924.46
RES22K-RC22H	R133	RC0603FR-1322KL	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R132	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R131	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R130	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R40	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R12	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76

Reliability Prediction Report

Assembly SUB-0736PCB/A **Model** Telcordia Issue 2 **Failure Rate** 2198.309822 FITs
Description ROHS SUB ASSY **Temperature** 21.00 C **MTBF** 454895 hours
Date 3/26/2009 8:54:38 **Environment** GF, GU - Ground Fixed, **Confidence** 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
RES10K-RC22H	R51	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES22K-RC22H	R73	RC0603FR-1322KL	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R90	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES3K3-RC22H	R76	RC0603FR-073K3L	Resistor			1	20	1	1.725997	579375343.76
RES22K-RC22H	R47	RC0603FR-1322KL	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R71	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R59	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R37	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES10K-RC22H	R23	2322 704 71003	Resistor			1	20	1	1.725997	579375343.76
RES22K-RC22H	R18	RC0603FR-1322KL	Resistor			1	20	1	1.725997	579375343.76
RES33K-RC22H	R142	RC0603FR-0733KL	Resistor			1	20	1	1.719279	581639319.48
RES4K7-RC22H	R39	RC0603FR-134K7L	Resistor			1	20	1	1.719279	581639319.48
RES4K7-RC22H	R25	RC0603FR-134K7L	Resistor			1	20	1	1.717045	582395942.29
DIO-BAT54/S	D16	BAT54SLT1G	Semiconductor		0		20	1	1.714945	583108978.09
DIO-BAT54/S	D30	BAT54SLT1G	Semiconductor		0		20	1	1.714945	583108978.09
RES4K7-RC22H	R3	RC0603FR-134K7L	Resistor			1	20	1	1.714814	583153549.36
RES22K-RC22H	R145	RC0603FR-1322KL	Resistor			1	20	1	1.712586	583912141.95
RES22K-RC22H	R149	RC0603FR-1322KL	Resistor			1	20	1	1.712586	583912141.95
RES15K-RC22H	R41	RT0603FR-1015KL	Resistor			0	20	1	1.710361	584671721.35
RES12K-0603/0.1	R57	RT0603BRE0712KL	Resistor			0	20	1	1.710361	584671721.35
RES4K7-RC22H	R44	RC0603FR-134K7L	Resistor			0	20	1	1.710361	584671721.35
RES12K-0603/0.1	R10	RT0603BRE0712KL	Resistor			0	20	1	1.710361	584671721.35
RES8K2-RC22H	R89	RC0603FR-078K2L	Resistor			0	20	1	1.710361	584671721.35
RES47K-RC22H	R53	RC0603FR-0747KL	Resistor			0	20	1	1.705920	586193845.73
RES100K-RC22H	R49	CRG 0603 1% 100K	Resistor			0	20	1	1.703704	586956393.28
RES10K-RC22H	R21	2322 704 71003	Resistor			0	20	1	1.703704	586956393.28
RES100K-RC22H	R28	CRG 0603 1% 100K	Resistor			0	20	1	1.703704	586956393.28
RES2K2-RC02H	R2	RC02H-2K2-DRM	Resistor			0	20	1	1.703704	586956393.28
RES2K2-RC02H	R61	RC02H-2K2-DRM	Resistor			0	20	1	1.703704	586956393.28
RES470K-RC22H	R87	RC0603FR-07470KL	Resistor			0	20	1	1.702597	587338038.96
RES4K7-RC22H	R20	RC0603FR-134K7L	Resistor			0	20	1	1.702597	587338038.96
RES82K-RC22H	R85	2322-7046-8203	Resistor			0	20	1	1.702597	587338038.96

Reliability Prediction Report

Assembly	SUB-0736PCB/A	**Model**	Telcordia Issue 2	**Failure Rate**	2198.309822 FITs
Description	ROHS SUB ASSY	**Temperature**	21.00 C	**MTBF**	454895 hours
Date	3/26/2009 8:54:38	**Environment**	GF, GU - Ground Fixed,	**Confidence**	60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
RES47K-RC22H	R86	RC0603FR-0747KL	Resistor			0	20	1	1.702154	587490766.70
RES1M-RC22H	R78	RC0603FR-071ML	Resistor			0	20	1	1.702154	587490766.70
RES1M-RC22H	R77	RC0603FR-071ML	Resistor			0	20	1	1.702154	587490766.70
RES1K-RC22H	R42	RT0603FR-071KL	Resistor			0	20	1	1.702154	587490766.70
RES1M-RC22H	R143	RC0603FR-071ML	Resistor			0	20	1	1.702154	587490766.70
RES330K-RC22H	R81	RC0603FR-07330KL	Resistor			0	20	1	1.702154	587490766.70
RES1M-RC22H	R34	RC0603FR-071ML	Resistor			0	20	1	1.701712	587643534.16
RES1M-RC22H	R46	RC0603FR-071ML	Resistor			0	20	1	1.701712	587643534.16
RESJ-RC21	R45	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R8	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R36	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RES3K3-RC22H	R141	RC0603FR-073K3L	Resistor			0	20	1	1.701491	587719932.79
RES220K-RC12H	R127	RC0805FR-10220KL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R126	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC11	R118	RC0805FR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R116	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC11	R111	RC0805FR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R115	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R75	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC21	R67	RC0603JR-130RL	Resistor			0	20	1	1.701491	587719932.79
RESJ-RC11	R114	RC0805FR-130RL	Resistor			0	20	1	1.701491	587719932.79
PLG-MOLEX2/0.1	CN2	22-27-2021	Connection				20	1	1.664484	600786644.81
DIO-S1M	D24	S1M	Semiconductor	2	17		20	1	1.385670	721672385.23
DIO-S1M	D23	S1M	Semiconductor	2	17		20	1	1.385670	721672385.23
C1U-25/1206/10	C41	GRM42-6X7R105K25	Capacitor	48			20	1	1.153447	866966784.09
DIO-S1M	D6	S1M	Semiconductor	1	9		20	1	1.105153	904851892.70
DIO-S1M	D10	S1M	Semiconductor	1	9		20	1	1.105153	904851892.70
DIO-S1M	D25	S1M	Semiconductor	1	8		20	1	1.089244	918067829.13
C100N-50/0805/10	C22	0805 2R 104 K9AB	Capacitor	45			20	1	1.011622	988511883.93
C100N-50/0805/10	C21	0805 2R 104 K9AB	Capacitor	45			20	1	1.011622	988511883.93
DIO-S1M	D19	S1M	Semiconductor		0		20	1	0.857224	1166556208.43
C100N-50/0805/10	C20	0805 2R 104 K9AB	Capacitor	40			20	1	0.824115	1213423114.54

Reliability Prediction Report

Assembly	SUB-0736PCB/A	**Model**	Telcordia Issue 2	**Failure Rate**	2198.309822 FITs
Description	ROHS SUB ASSY	**Temperature**	21.00 C	**MTBF**	454895 hours
Date	3/26/2009 8:54:38	**Environment**	GF, GU - Ground Fixed,	**Confidence**	60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
FUS 5.0A – 20 MM –		FUS 5.0A – 20 MM – GQB	Miscellaneous				20	1	0.669262	1494182817.26
C100N-50/0805/10	C11	0805 2R 104 K9AB	Capacitor	30			20	1	0.551427	1813475891.50
C100N-50/0805/10	C10	0805 2R 104 K9AB	Capacitor	30			20	1	0.551427	1813475891.50
C100N-50/0805/10	C8	0805 2R 104 K9AB	Capacitor	30			20	1	0.551427	1813475891.50
C100N-50/0805/10	C5	0805 2R 104 K9AB	Capacitor	30			20	1	0.551427	1813475891.50
C4U7-25V/1206/10	C59	C1206C475K3RAC7800	Capacitor	26			20	1	0.468019	2136663255.44
C4U7-25V/1206/10	C58	C1206C475K3RAC7800	Capacitor	26			20	1	0.468019	2136663255.44
C100N-50/0805/10	C24	0805 2R 104 K9AB	Capacitor	24			20	1	0.431173	2319253544.27
C1U-25/1206/10	C34	GRM42-6X7R105K25	Capacitor	20			20	1	0.365955	2732577726.19
C1U-25/1206/10	C42	GRM42-6X7R105K25	Capacitor	20			20	1	0.365955	2732577726.19
C4U7-25V/1206/10	C37	C1206C475K3RAC7800	Capacitor	13			20	1	0.276915	3611218990.14
C1U-25/1206/10	C32	GRM42-6X7R105K25	Capacitor	13			20	1	0.276915	3611218990.14
C4U7-25V/1206/10	C36	C1206C475K3RAC7800	Capacitor	13			20	1	0.276915	3611218990.14
C1U-25/1206/10	C39	GRM42-6X7R105K25	Capacitor	13			20	1	0.276915	3611218990.14
C10N-50/0805/10	C57	0805 2R 103 K9AB	Capacitor	13			20	1	0.274653	3640952727.57
C100P-50/0603/10	C60	222258616601	Capacitor	10			20	1	0.242866	4117496717.02
C100P-50/0603/10	C18	222258616601	Capacitor	10			20	1	0.242866	4117496717.02
C100N-50/0805/10	C23	0805 2R 104 K9AB	Capacitor	10			20	1	0.242866	4117496717.02
C100P-50/0603/10	C15	222258616601	Capacitor	10			20	1	0.242866	4117496717.02
C100N-50/0805/10	C25	0805 2R 104 K9AB	Capacitor	10			20	1	0.242866	4117496717.02
C100N-50/0805/10	C27	0805 2R 104 K9AB	Capacitor	10			20	1	0.242866	4117496717.02
C1U-25/1206/10	C33	GRM42-6X7R105K25	Capacitor	7			20	1	0.216526	4618386426.45
C100N-50/0805/10	C7	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100P-50/0603/10	C4	222258616601	Capacitor	7			20	1	0.211264	4733407693.67
C56P-50/0603/10	C2	2238 86715569	Capacitor	7			20	1	0.211264	4733407693.67
C56P-50/0603/10	C1	2238 86715569	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C9	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C6	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C12	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C10N-50/0805/10	C13	0805 2R 103 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C14	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C10N-50/0805/10	C17	0805 2R 103 K9AB	Capacitor	7			20	1	0.211264	4733407693.67

Reliability Prediction Report

Assembly SUB-0736PCB/A **Model** Telcordia Issue 2 **Failure Rate** 2198.309822 FITs
Description ROHS SUB ASSY **Temperature** 21.00 C **MTBF** 454895 hours
Date 3/26/2009 8:54:38 **Environment** GF, GU - Ground Fixed, **Confidence** 60 %

Part Number	Ref Des	Mfr Part Number	Category	Voltage Ratio (%)	Current Ratio (%)	Power Ratio (%)	Temp Rise (C)	Qty	Failure Rate (FITs)	MTBF (hours)
C100N-50/0805/10	C19	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C10N-50/0805/10	C28	0805 2R 103 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C30	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C31	0805 2R 104 K9AB	Capacitor	7			20	1	0.211264	4733407693.67
C100N-50/0805/10	C16	0805 2R 104 K9AB	Capacitor	4			20	1	0.186813	5352937018.76
XTL-4MHZ/SXE	Y1	X4M000000S002	Miscellaneous				20	1	0.121808	8209608556.00
E-47/35/ELOZ	C48	RP1V476M6L011PC48	Capacitor	64			20	1	0.000683	1464874450508.-
E-47/35/ELOZ	C49	RP1V476M6L011PC48	Capacitor	64			20	1	0.000683	1464874450508.-

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 13th 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.. T20	FCB20N60F	Semiconductor	4	12.9	99323675.77
New Component	HGTG5N120BND	T17.. T20	5N120BND	Semiconductor	4	20.3	Unknown

*FIT values taken from manufacturers website (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 Relex 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.

2. 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)

3. 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.
4. 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 Relex cumulative reliability calculation.

Change Summary

A number of small changes have been made to the bill of materials that was used by Relex 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 Relex 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 verses temperature. As the ambient temperature increases the Failures In Time (FITs) will increase and the Mean Time Between Failures (MBTF) 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*

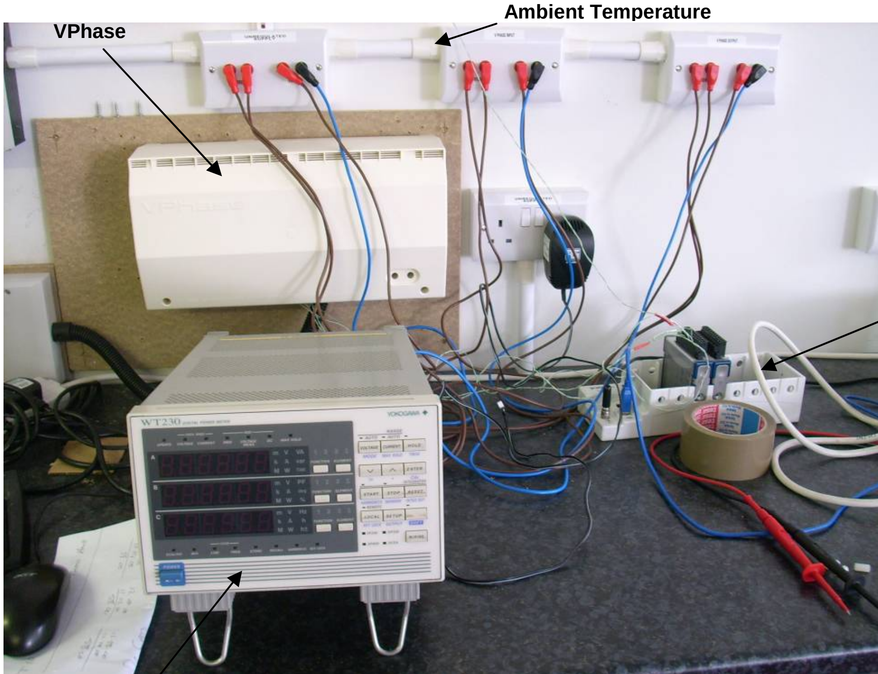


Figure 2. *Test Setup*

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 actualy 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*

	VX1 Input			VX1 Output			Temperatures (°C)			
Date	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 temperture 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 avarage 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.

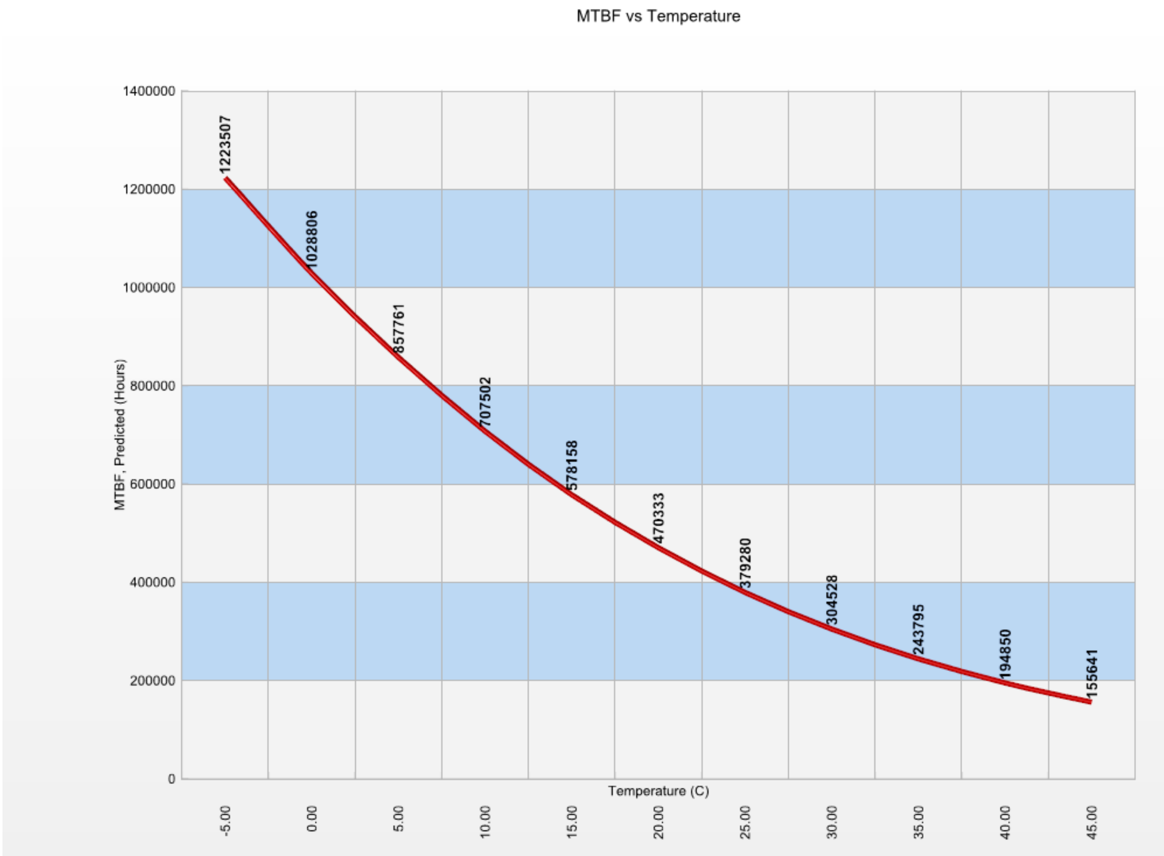


Figure 3. *MTBF vs Temperature*

Summary

A number of small changes have been made to the bill of materials since the Relex 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 Relex 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

Mean Temp Site 60	**10.9**	**29.0**

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_2 Saving for the Trial

	Reading (DECC[8], kWh)	Trial (kWh)	$kgCO_2/kWh$	$kgCO_2$
Electricity Consumed	4270	4592	0.591	2714
Gas Consumed	16505	17748	0.206	3656
Electricity Saved @ 5.2%		238	0.591	141
Whole-House %-CO_2 emission saving				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[19]; 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[18] , the English House Condition Survey 2005[19], and the European Commission[20], 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[21].

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.

[18] DECC, Energy Consumption in the UK, Domestic Data Tables 2010 Update, available at www.decc.gov.uk, accessed 7th September 2010

[19] Dept. for Communities and Local Government, Energy Use in Homes 2005, published 2008.

[20] 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

[21] The Energy Saving Trust, The Rise of the Machines, available at www.energysavingtrust.org.uk, accessed 7th 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%.

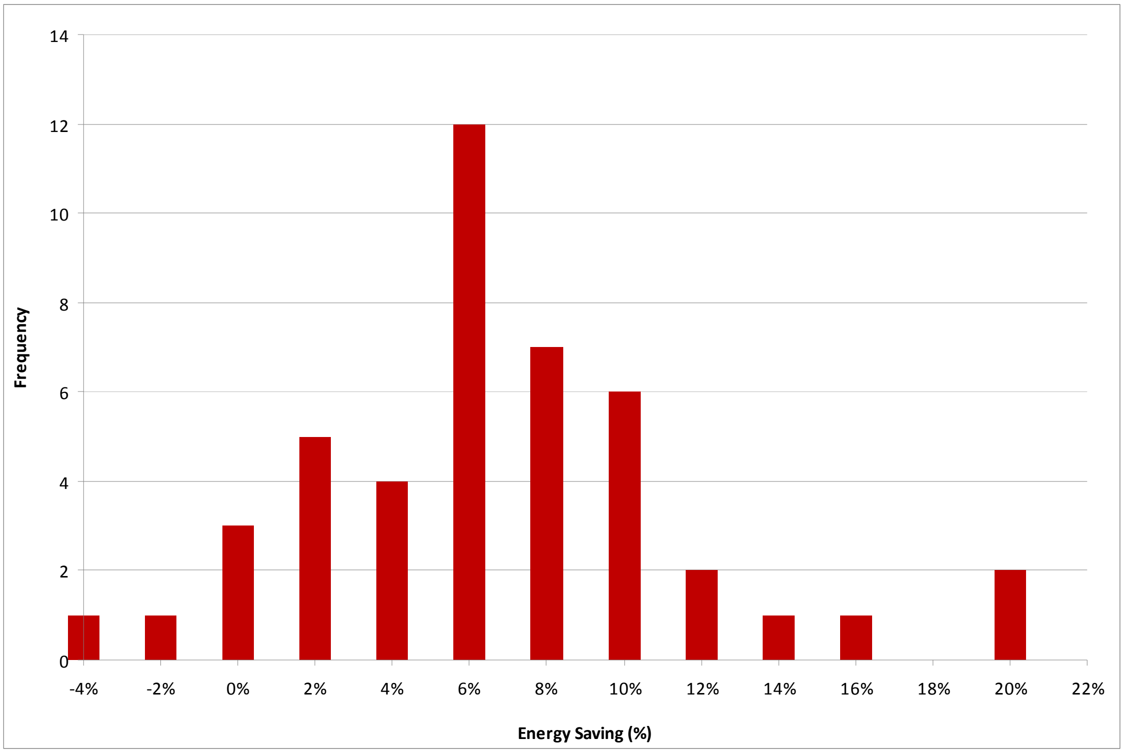

Figure 22: Percentage Energy Savings of Rebased Results
Note x-axis label denotes the lower end of the bin, i.e. there were 3 results which were between 0% and 2%.

Table 17: Estimated Energy Consumption of Sites with Electric Heating

	Appliance Category	Percentage of UK Energy Consumption	Gas for All Cooking and Hot Water	Electric Immersion Only	Electric Cooking Only	Electric Shower and Electric Cooking	Electric Immersion and Cooking	Electric Immersion, Cooking and Shower	Electric Immersion and Shower
VX1-Supplied Load	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
Non-VX1 Supplied Load	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
Ratios of Loads	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

	Trial	Rebased
Mean Electricity % Saving	5.2%	6.3%
Number of Sites	45	45
Standard Deviation of Site Energy Saving %	4.7%	5.8%
CL ± %	1.4%	1.7%