Electricity Association

Load Research Group

Street Lighting
Load Research Project

For ELEXON's Unmetered Supplies User Group (UMSUG)

Report on the findings of field measurements taken on 35 Watt Low Pressure Sodium lamps (35W SOX) fitted with Low Loss Control Gear

May 2002

The Electricity Association

The Electricity Association (EA) operates to provide both a collective voice on issues of common concern to the major electricity companies in the UK, and a range of specific professional services. Load research is one of the foremost of these services.

The Electricity Association's Load Research Group (LRG) provides a range of services for capturing, processing, and interpreting data on the detailed pattern of electricity usage - by half-hour throughout the year, for a large number of electricity customers and customer types. Key skills within the Group include statistical, econometric and electrical engineering expertise.

LRG have established, and regularly update, a comprehensive database. This draws on electricity usage data mainly from dedicated recording instrumentation, installed amongst representative samples of customers in the UK. We also carry out localised monitoring projects and studies.

LRG's database is also used to produce the Load Profile data used in NETA, the electricity settlement system of England and Wales and also for the system used in Scotland. Some 26 million electricity customers have their demand estimated from LRG's load research, every half-hour, every day.

Work is also undertaken for other organisations, UK and internationally. LRG has close links with a number of overseas counterparts.

Report on the findings of field measurements taken on 35 Watt Low Pressure Sodium lamps (35W SOX) fitted with Low Loss Control Gear

1 Project Background

1.1 The load ratings quoted in BSCP 520 are based on values agreed by the Joint Lighting Committee (an ESI and Lighting Authority Liaison Group) in 1987. These ratings were taken from manufacturers catalogue values without any field testing. A limited amount of practical field monitoring and also tests by independent authorities indicated that actual loads were higher than the quoted values. A small scale research project carried out by Yorkshire Electricity Group in 1996 suggested that in less than 7% of lamps was the load within ± 2% and in 77% of the sample the load was greater.

1.2 The Unmetered Supplies User Group therefore recommended that this research project should be undertaken to establish the load of one of the most popular (based on total system load) lamp types and to provide guidelines for possible future projects.

2 Management Summary

2.1 LRG developed a precision meter and data logger to fit within the lamp column. A street lighting contractor, Southern Electric Contracting Ltd (SEC) was employed to install and remove the equipment.

2.2 A total of 327 35W SOX lamps with low loss control gear were monitored, on a half-hour basis, for an average of three months each in four areas of the country during 2001. Over 1.4 million half-hourly measurements of both Wh and VArh were recorded.

2.3 The average recorded electrical load when the unit was illuminated was found to be 58.4 Watts. The average reactive power was measured as 64.1 VAr.

2.4 Analysis of the recorded values gives a sample precision of ± 1.55 Watts at 99% confidence. An explanation of the sample size and selection is given in Appendix A.

2.5 Additional data was gathered on the lamp and control gear manufacturer and model along with spot readings of the load. A small sample of a second lamp type, 70W SON, were monitored simultaneously to the main lamp type to determine the variability within this type for a possible future research project. Analysis of the 70W SON results shows a sample size of 200 would be necessary to give the required accuracy.

3 Sample selection

3.1 Work by Yorkshire Electricity in 1995 gave an indication of the variability within a sample of 35W SOX lamps. A sample precision of ± 2% with 99% confidence was suggested and analysis of the Yorkshire data showed this would require a sample size of 265. In addition it was decided to monitor a small number of 70W SON lamps to determine the variability within this lamp type, and 25 lamps was considered sufficient for this purpose.

3.2 To limit travelling costs and also the amount of monitoring equipment required, it was decided to limit the monitoring of installations to four of the twelve Distribution Company's areas. To ensure a good geographical spread, areas in the north-west, midlands, south-west and eastern England were chosen. In each area three lighting authorities were selected who fulfilled the requirements of a substantial number of 35 Watt low loss SOX lamps and who also had a good quality detailed inventory. During the project one authority asked to withdraw and another was found not to have an accurate inventory, both were replaced so fourteen authorities are represented in the final sample. Within each lighting authority lamps were randomly chosen in proportion to the lamp population in the area.

3.3 To ensure the full sample size was achieved a target total of 400 lamps were to be monitored, consisting of 375 35W SOX and 25 70W SON lamps. To make this cost effective, 25 sets of monitoring equipment were despatched to each of the four Distribution Company areas. The 25 sets were transferred to new lamps every three months on average to cover 100 lamps in each area.

3.4 Full details of each installation were collected when the monitoring equipment was installed and removed. Details of the installation procedure and the information collected are in Appendix B. A national street lighting contractor, SEC Ltd, were employed to install and remove the equipment because they had the both the necessary technical knowledge and also suitable equipment to gain access to the luminare.

3.5 The installation contractor was provided with a list of randomly selected lamp locations. They visited each location in turn either installing the logger or, if the column was not suitable, noting the reason and proceeding to the next one on the list until the correct number of lamps had equipment installed.

3.6 The reasons for not being able to install loggers have been analysed as follows: -

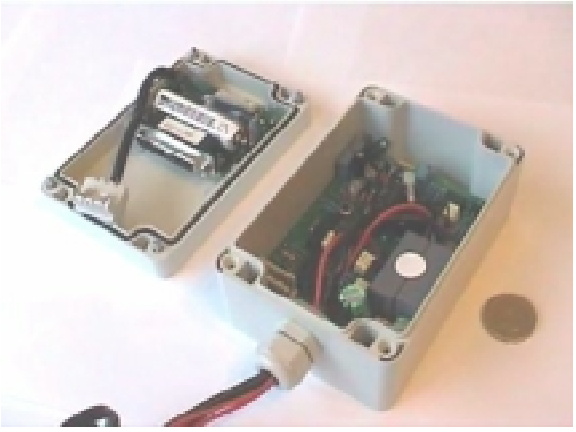
No room in column base for monitoring equipment	64
Wrong lamp type	24
Anti vandal area - door banded	12
Unable to gain access e.g. car obstructing lamp	15
No supply e.g. remotely controlled or mains failure	3
Security key required	2
Unable to locate lamp	2
Day burning	2
Lamp not operating	1
No control box	1
Total	126

4 Monitoring Equipment

4.1 In light of the experience of Yorkshire Electricity it was determined that the monitoring equipment should be as small as possible and housed in a water proof case. Willow Electronics Ltd were commissioned to develop with the EA a compact meter able to continuously monitor kWh and kVArh housed with a data logger within an IP65 rated case. The unit has its own internal power supply and is capable of recording for a year without attention.

4.2 The finished unit was sent to London Electricity's UKAS accredited laboratory in Bexleyheath, (now renamed to The Calibration Laboratory ECS Metering Services Ltd) for accuracy testing.

4.3 As each unit was returned from site it was downloaded and then checked for accuracy before being returned for installation at a new location.

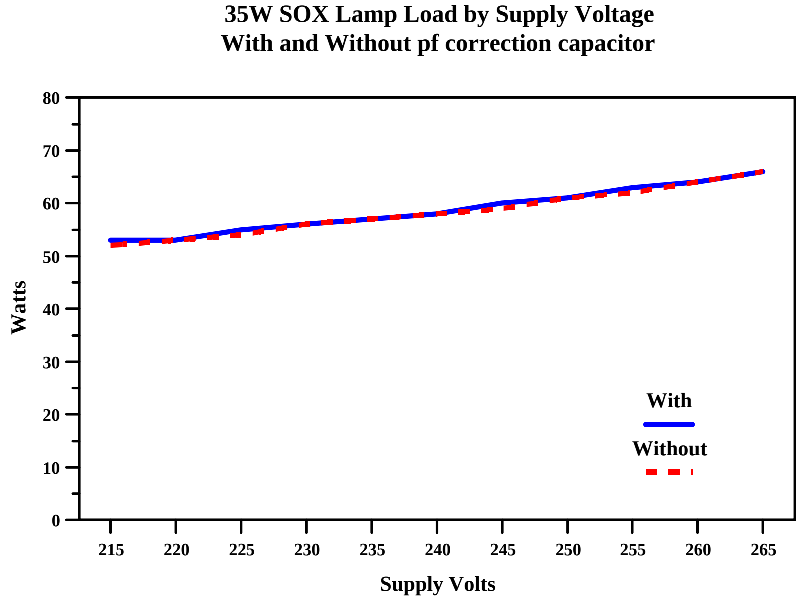


4.4 The photographs above show the monitoring unit against a £1 coin for size comparison

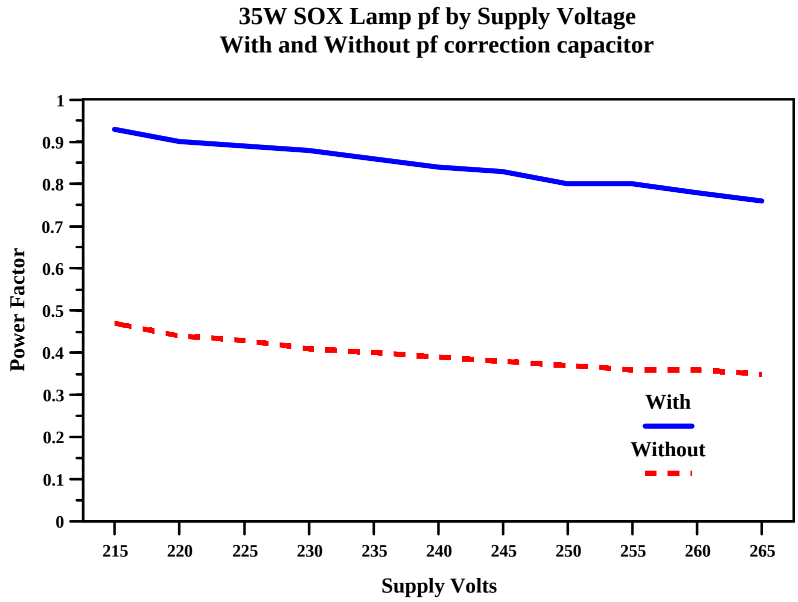
5 Lamp Laboratory Tests

5.1 To gain some experience of the operating characteristics of a typical lamp, a new 35 Watt SOX luminare with integral control gear was obtained for laboratory testing by the EA. The results given below show the variation in demand for a change in supply voltage with and without the power factor correction capacitor connected. These results are included for illustrative purposes only and are not used in the average load calculations.

5.2 Measurements were taken using a precision 0.1 Ohm resistor to give the current signal as this gave a more accurate measurement at low power factor than the Fluke current clamp.



5.2 The graph below shows variation in power factor over a range of supply voltages, again with and without the power factor correction capacitor connected.

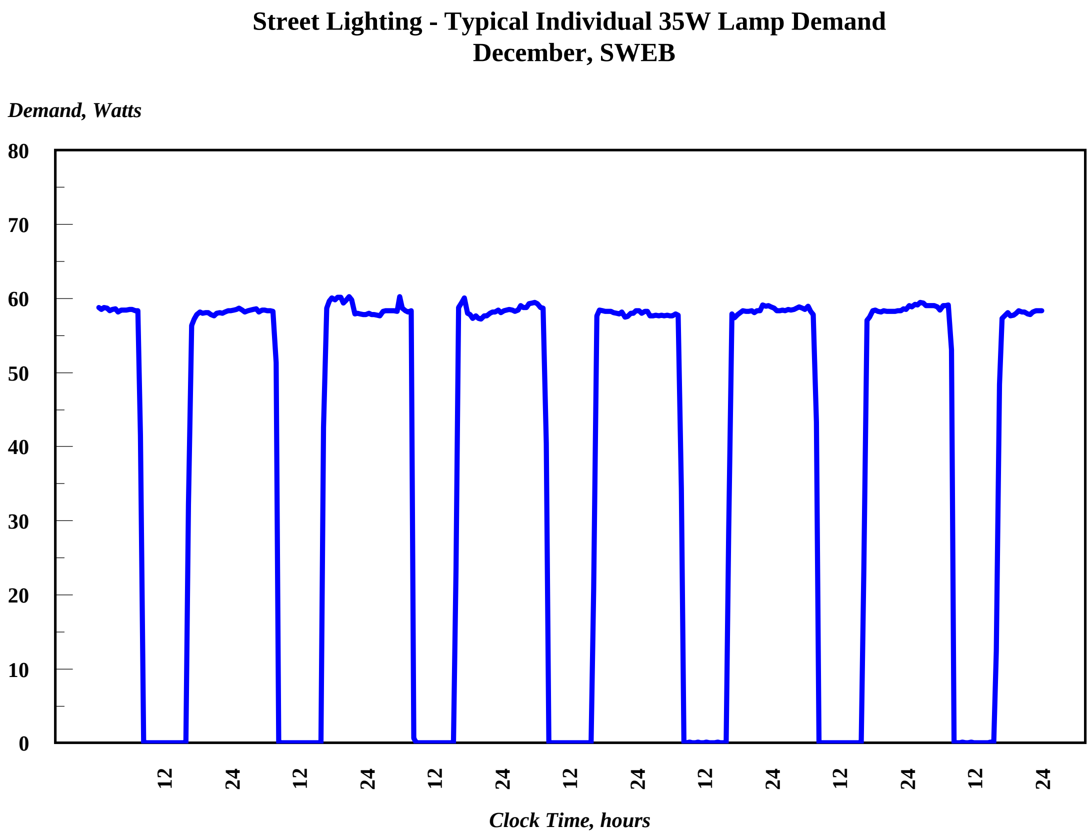


6 Data Analyses

6.1 The recorded data for each location was processed by selecting all the half hour periods when the unit was illuminated; then discarding the first and last half hour periods of each night because this is when switching took place and therefore the unit was not operating for the full half hour period. The total demand was then calculated by averaging the selected values.

6.2 The monitoring equipment recorded the total of the lamp, control gear and photo electric control load. In order to determine the lamp and control gear load only, the night load of the photo electric control was determined from the manufactures' information and this was subtracted from the total demand value to determine the average net demand for each location.

An example of the recorded data is given below.



7 *Key Results*

7.1 The results for recorded demands by area giving the minimum maximum and average are shown below.

Street Lighting - Recorded Demands

	Number of Lamps	Min Recorded Demand (W)	Max Recorded Demand (W)	Average Recorded Demand (W)
35W Lamps				
SWEB	95	33.3	79.7	56.5
Eastern	78	35.9	87.8	61.0
Midlands	71	42.7	146.1	60.4
Norweb	83	34.3	128.6	56.5
All 35W Lamps	**327**	**33.3**	**146.1**	**58.4**
70W Lamps				
All 70W Lamps	26	65.0	100.8	88.3

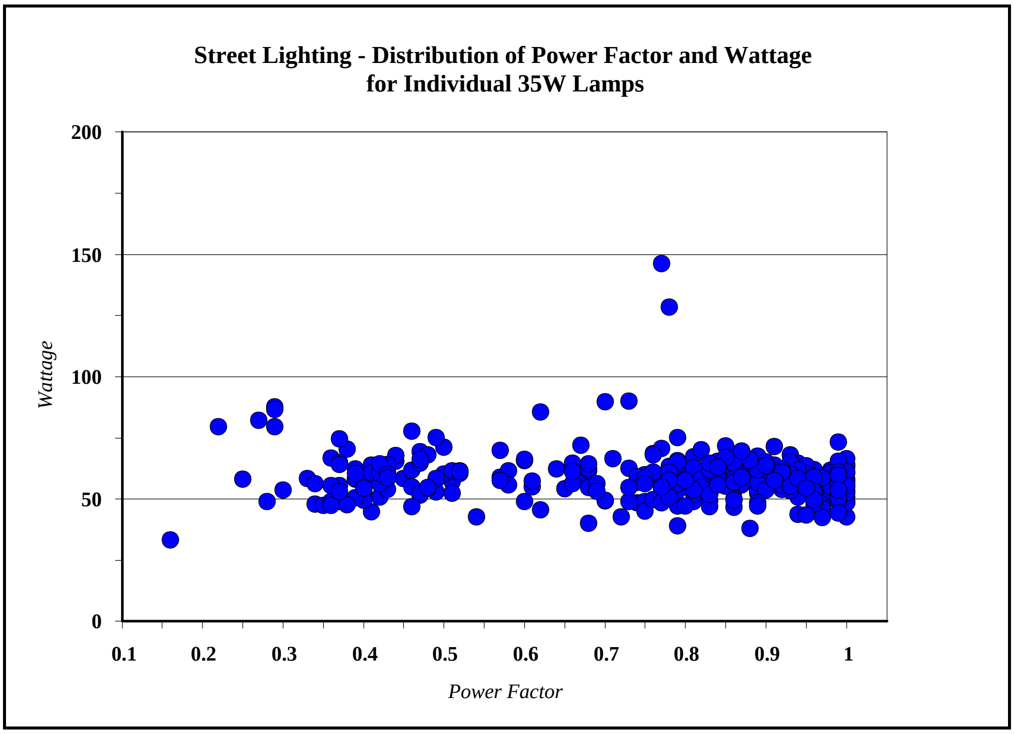
7.2 Reactive power measurement results

Street Lighting - Recorded Reactive Power

	Number of Lamps	Min Recorded Reactive Power (VAr)	Max Recorded Reactive Power (VAr)	Average Recorded Reactive Power (VAr)
35W Lamps				
SWEB	95	0	355.4	67.1
Eastern	72	0	288.7	77.7
Midlands	71	3.7	136.3	48.7
Norweb	80	0	170.7	62.2
All 35W Lamps	**318**	**0**	**355.4**	**64.1**
70W Lamps				
All 70W Lamps	25	0	144.9	63.2

7.3 The distribution of power factor and Wattage values is shown below. The recording equipment is designed to be accurate when measuring loads with a low power factor.

7.4 The graph below shows two lamps with an average load above 100 W. These two lamps were also found to be all day burning. Investigation of the detailed load pattern of these lamps shows that they exhibit the same characteristic load pattern as other all day burning lamps. They were therefore included in the calculation of the overall average Wattage value. However, there inclusion had no material effect on the overall average Wattage value because of rounding.



7.5

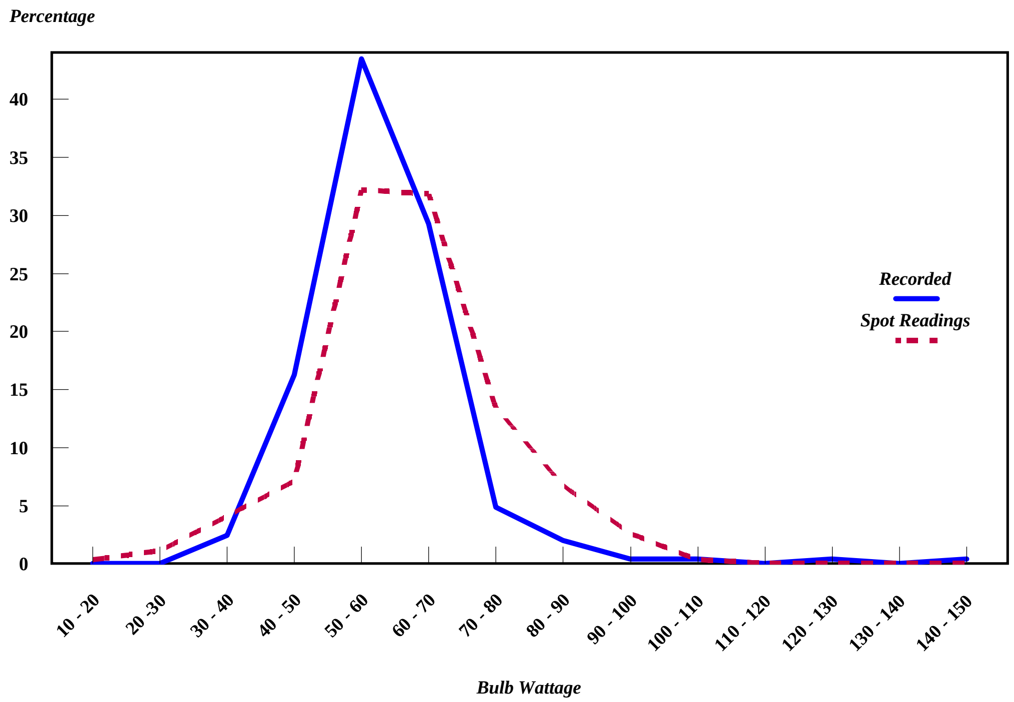
Spot readings

Street Lighting - Spot Reading Demands

	Number of Lamps	Min Spot Readings (W)	Max Spot Readings (W)	Average Spot Readings (W)
35W Lamps				
SWEB	95	39.0	96.0	64.2
Eastern	92	31.0	87.5	62.4
Midlands	80	26.0	80.0	61.9
Norweb	46	20.0	110.0	61.3
All 35W Lamps	313	20.0	110.0	62.7
70W Lamps				
All 70W Lamps	23	46.0	140.0	76.5

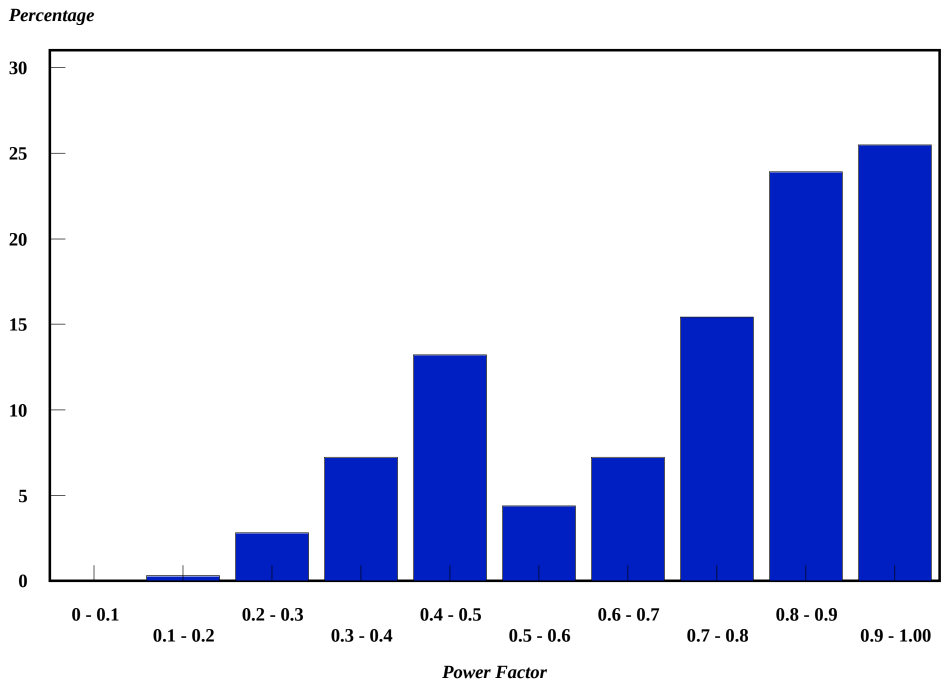
7.6 Distribution of Wattage Values

Street Lighting - Comparison of Wattage Distribution between Recorded Demand and Spot Readings, for Individual 35W Lamps



7.7 Distribution of Power factor Values

Street Lighting - Power Factor Distribution for Individual 35W Lamps



7.8 Voltage values

Street Lighting - Fluke 39 Spot Readings

	Number of Lamps	Min Spot Readings (V)	Max Spot Readings (V)	Average Spot Readings (V)
35W Lamps				
SWEB	95	235	260	244
Eastern	92	237	247	242
Midlands	92	233	250	243
Norweb	92	229	257	244
All 35W Lamps	371	233	260	243
70W Lamps				
All 70W Lamps	31	236	253	244
All Lamps	402	233	260	**243.45**

8 *Lessons Learned*

8.1 This was a major exercise to monitor street lamp loads on a wide geographic basis. A number of factors are now evident that were unknown or difficult to asses at the start of the project.

8.2 The equipment was purpose designed to fit in a small water proof case, though the metering and data logging circuitry were well known and proven. In practice two of the units were completely submerged in water during the floods and consequently failed. The level of water proofing was upgraded on the remaining units as they were exchanged. One additional unit was reported stolen from the lamp column. Overall the equipment performed very well in an unfriendly environment for precision metering.

8.3 The validation of the lamp load shapes and values led to the rejection of a small number of sample lamps because of erratic or all zero readings. The remaining lamps in the sample, including some all-day-burning, produced reliable readings.

8.4 The installation procedure was performed successfully, though a faster turn around of equipment should be possible in future. One point of concern is that around a quarter of the locations visited were found to be unsuitable. The most common reason being 'no room' in the column, with a lamp type different to that shown in the inventory being the second most common reason.

8.5 Finally, analysis of the data shows that recording a lamp for more than a couple of weeks does not give any improvement to the accuracy of measurement of that lamp. It should be possible to repeat the exercise with shorter recording periods, the installation and exchange process being the limiting factor.

DAC/IPZ
May 2002

Appendix A

Sample Size and Selection

A1 As in any load research project the precision of sample estimates is influenced by sample size. An increase in sample size will lead to an increase in the precision of sample average wattage as an estimator of the population average wattage but sampling costs will also increase and ultimately the sample size is determined as a balance of precision and cost

A2 Public lighting load measurements published by Yorkshire Electricity in 1996 included measured wattage for thirty-six 35W SOX lamps with low loss control gear. These results provided a guide to the relationship that could be expected between sample size and precision in the UMSUG national project.

A3 This prior analysis showed that, other things being equal, precision of ±2% at 99% confidence would be achieved for the average measured wattage with a simple random sample of 265 lamps while over 1,000 would be required to achieve precision of ±1% at 99% confidence. It was accepted that the target level of precision should be ±2% at 99% confidence while the target sample size would be rounded up to 300.

A4 Precision of ±2% at 99% confidence means that the interval (sample average - 2%, sample average + 2%) is a 99% confidence interval for the population (i.e., all 35W SOX lamps in England & Wales) average wattage or, in other words, the interval (sample average - 2%, sample average + 2%) has a probability of 0.99 of containing the true population average. It can be assumed that for even moderately large sample sizes the sample mean will have a normal probability distribution with mean equal to the population mean and variance equal to

$$\left(1-\frac{n}{N}\right)\frac{S^2}{n}$$

where n, N and S^2 are the sample size, population size and population variance respectively. This leads to the fact that the interval

$$\bar{x} \pm t_{.995,n-1}\sqrt{1-\frac{n}{N}}\;\frac{s}{\sqrt{n}}$$

yields a 99% confidence interval for the population average wattage, where $\bar{x}$ is the sample average wattage, s^2 is the sample variance and $t_{.995,n-1}$ is the value of t for which the cumulative Student's t-distribution function with n-1 degrees of freedom is equal to 0.995. Since the sample size is likely to be very small in comparison to the population size the factor $\sqrt{1-\frac{n}{N}}$ can be ignored as it will be very close to 1. Therefore, an approximate 99% confidence interval is given by

$$\bar{x} \pm t_{.995,n-1}\;\frac{s}{\sqrt{n}}$$

In order to obtain precision of ±2% at 99% confidence means that n needs to be sufficiently large so that

$$\frac{t_{.995,n-1} \frac{s}{\sqrt{n}}}{\bar{x}} = 0.02$$

i.e., $$\sqrt{n} = \frac{t_{.995,n-1}}{0.02} \frac{s}{\bar{x}}$$

For the prior Yorkshire sample the values of $\bar{x}$ and s^2 were approximately 60.4 W and 57.4 W respectively, implying that a sample size of 265 would be required to achieve ±2% precision at 99% confidence.

A5 Of course, the calculation of required sample size in paragraph A4 is only a projection from a prior sample, much smaller in size, and so cannot guarantee the level of precision that will actually be achieved when the data is collected. Nothing can, since the population variance is just as much unknown as the population mean. However, this method, a standard practice for determining the size of a sample to be used in sampling projects, would be expected to produce a level of precision which is close to what is desired, although it could turn out to be a little better or a little worse. Although the calculated sample size was 265, the target sample size was set at 300 to allow for a slightly higher population variance compared with the Yorkshire data.

A6 It may come as a surprise to some that a sample of less than 300 lamps from such a large population can give such a precise estimate. However, for any given fixed sample size in simple random sampling, what matters most regarding the likely precision of an estimate is the spread of the population values about the mean (as measured by the standard deviation) relative to the mean. The smaller the variation then the smaller the sample size is required until in the limit if there is no variation then, trivially, a sample size of just 1 is required! As the lamps are fundamentally of the same type and likely to be on, by and large, at similar times one would expect the relative spread of peak wattage values to be much smaller than, say, the spread of peak demand values of domestic customers, in which case a sample of 300 would be nowhere near enough to achieve the same level of precision. Furthermore, it matters little what the actual population size is since it is so large relative to the sample size. It would make a deal of a difference if a sample of 300 was taken from a population of 600 compared with a sample of 300 from a population of one million, where the sampling fractions are 50% and 0.03% respectively. However, other things being equal, it would not matter much if the population size was 30,000 or 300,000 or 1,000,000 or 3,000,000, the sampling fractions in these cases being 1%, 0.1%, 0.03% and 0.01% respectively. If the sampling fraction $\frac{n}{N}$ is small, implying that the factor $\sqrt{1-\frac{n}{N}}$ is close to 1, then it can be ignored.

A7 In order to keep costs down the sampling scheme used was not in the event a strictly simple random sample. To select a simple random sample from a complete inventory of all 35W SOX lamps with low loss control gear in England & Wales and then install monitoring equipment for the chosen sample would have involved enormous administrative and travelling costs. Instead, four distribution regions were selected i.e., SWEB (now part of Western Power Distribution), Eastern Electricity (EPN Distribution), Midlands Electricity (GPU Power Distribution) and NORWEB (United Utilities Electricity). Within those regions the towns/districts/parishes with the highest number of lamps of the correct type were chosen and then simple random samples were selected within each town/district/parish. No appreciable bias is assumed to arise from this approach.

Appendix B

Monitoring Equipment Installation Procedure

Purpose

These notes are for guidance in the installation of Street Lighting Monitoring Equipment. The equipment is sealed in an IP65 rated waterproof enclosure and will accurately monitor the lamp circuit load. A data logger is included within the enclosure to continuously record the pattern of use.

1 Safety

1.1 Your company's safety regulations must be fully observed when installing or removing Electricity Association equipment.

1.2 Ensure that the equipment is installed in a safe location within the lamp pillar.

2 Initial Check

2.1 Arrive at the chosen lamp location.

2.2 If the pillar door has been secured with bands, then this indicates a high vandalism area. Do not install the equipment. Note this on the Site Detail Form (IN12 F1) and travel to the next substitute lamp.

2.3 Remove pillar door, check there is sufficient room for the monitoring equipment in the pillar. Consider if repositioning the lighting control equipment on the board would allow room for the monitoring equipment. If there is insufficient room note this on the Site Detail Form (IN12F1), refit the pillar door and travel to the next substi tute lamp.

2.4 Raise the platform and inspect for the correct lamp / control gear type. Record the lamp and control gear details on the Site Detail Form .

2.5 If the wrong lamp / control gear type is found, note this on the Site Detail Form. Refit the pillar door and travel to the next substitute lamp.

2.6 Cover the Photo-electric Control Unit (PECU) to check the lamp operates. If the lamp fails to operate, note this on the Site Detail Form. Refit the pillar door and travel to the next substitute lamp.

3 Photo-electric Control Unit (PECU) Check

3.1 Fit the PECU adapter, refit PECU, take measurements of Volts and milliamps using the Robin Multimeter with the PECU uncovered and again with it covered allowing 30 seconds for the PECU to settle to the correct switch state. Record readings on the Site Detail Form. Remove the PECU adapter and refit the PECU.

3.2 Cover the PECU to switch on the lamp and lower the platform.

3.3 In the case of a two part PECU; firstly, disconnect the wire from the 'Load' L te rminal on the relay control unit to prevent the lamp from operating. Then, measure the current and voltage in the live supply to the relay control unit, with the photocell covered and uncovered. Reconnect these wires and check the lamp operates.

4 Installation of the monitoring equipment

4.1 The monitoring equipment should be positioned so that it is unlikely to be immersed in water.

4.2 The equipment should be connected to a continuous mains supply.

4.3 Isolate the mains supply and connect the monitoring equipment as in fig.1.

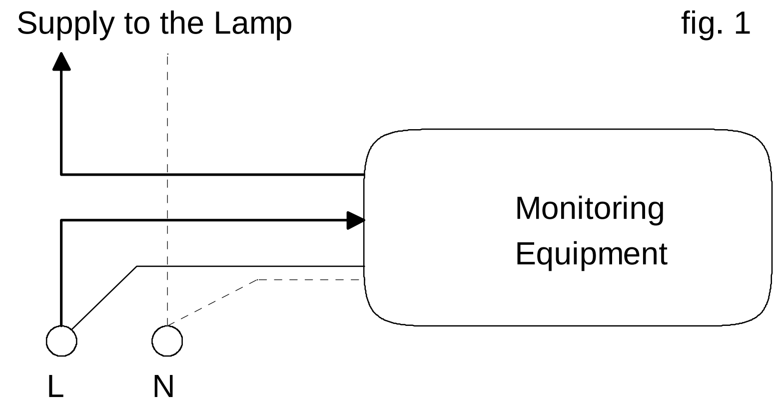


fig. 1

5 Spot check Readings

5.1 Connect the Fluke 39 Power Meter spot check equipment to measure the load of the total lamp, control gear and PECU circuit.

5.2 Restore the mains supply, allow at least 10 minutes for the lamp to stabilise, take spot check readings of Volts, Amps and Watts and record these on the Site Detail Form.

5.3 Disconnect the spot check equipment.

6 Restore Street Lamp Integrity

6.1 Restore the mains supply and check the lamp is still operating.

6.2 Refit pillar door.

6.3 Remove PECU cover.

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STREET LIGHTING PROJECT
SITE DETAIL FORM

IN12F1
Rev 3

Site Location	Monitor / Logger used WL _ _ _ _ TL _ _ _ _

Lamp Details		Control Gear Details	
Manufacturer		Manufacturer	
Rating (Watts)		Type code	
Type code			
Date of lamp Manufacture			
Date of lamp installation			

Fluke 39 Spot Readings	
Volts	
Amps	
Watts	

Photo-electric Control Unit (PECU)				
Robin Multimeter Readings			**PECU Details**	
	Uncovered	Covered		
Volts			Manufacturer	
Milliamps			Type code	
			Year of Manufacture	

Comments / Problems			
Signed		Date / Time	