Power Factor Correction for Unmetered Supplies

An Environmental Discussion Document

YALE

YORKSHIRE AND LANCASHIRE ENGINEERS

Prepared by: **YALE Group** Issued: **April 2007** Version: **2.1**

Contents

Photographs:

- **Front Cover**
  One of the thirteen wind turbines on Ingbirchworth Moor near Penistone, South Yorkshire. The scheme was funded by Yorkshire Water Limited and the former Yorkshire Electricity Group Limited which is now npower. Both companies are currently working with YPO and its members on a single meter, multi-utility AMR trial.
- **Back Cover**
  Amey Plc/Wakefield MDC - Bodmin Drive, Normanton, Wakefield, West Yorkshire using fully electronic gear and SON lamp technology. Picture courtesy of Paul Medlock - City of Wakefield MDC

1. Statement by Steve Atherton,
Director of Yorkshire Purchasing Organisation

Yorkshire Purchasing Organisation (YPO) purchases and manages energy in complete collaboration with the local authorities who use the Consortia's utility contracts.

Since its formation in 1974 and, as new markets have opened and matured, the organisation has continued to network with its user groups and advisory panels to aggregate solus demand. In this way, bespoke corporate and commercial purchasing decisions are made, with each user benefiting from the same competitive wholesale price allied to comprehensive back-office support and added value services provided by YPO and the relevant utility supplier.

Increased geopolitical tension and diminishing reserves leading to rising energy prices and the many issues surrounding the need to care for our environment have led the user groups to reassess their policy. As a result there is now a greater emphasis on the removal of risk, the security of supply, monitoring and prudent use, with moves towards a wider involvement in electronic billing, remote metering, reduction in emissions, carbon management and the minimisation of waste.

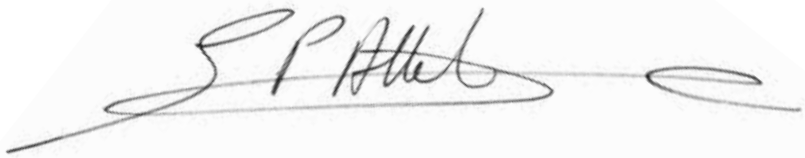
During 2003, the YPO specialist Street Lighting Engineers Group formalised its trading status which involved gaining full certification to British Standard Code of Practice 520. With more accurate usage now certain and, following an open tender, the winning supplier offered more attractive prices with the result that circa £2 million was saved by YPO's participating authorities.

For some time, the Group had been aware of the possible fiscal consequences posed by poor Power Factor correction. The increase in power taken due to poor capacitance is now being recognised as a loss by the Distribution Network Operators who could place responsibilities on local authorities to rectify the situation and legitimately seek to apply financial penalties. With several Lancashire based Authorities now party to YPO arrangements, it seemed an ideal opportunity to jointly research the issue and broaden the discussions between the YPO Panel and the authorities who make up GMADE – the Greater Manchester Association of District Engineers. During 2005, the two group chairman met and established a sub group under the acronym of YALE - Yorkshire and Lancashire Engineers. Since its inception, the Group has worked with United Utilities, CE Electric UK (formerly Yorkshire Electricity Distribution) and npower to prepare the environmental discussion document now before you 'Power Factor Correction for Unmetered Supplies'.

The findings are impressive. Projections on a national basis could see 500,000 fewer tonnes of CO_2 being emitted into the atmosphere – potentially saving energy equivalent to that produced by a small power station.

The Group is to be commended for its findings in highlighting this serious problem. At a time when grants are being made available via the Department for Environment, Food and Rural Affairs (defra) for waste recycling initiatives, it would appear that the ability to save energy equivalent at today's values of circa £100 million every year, for an initial investment of £30k per annum in each local authority, is certainly worthy of national focus and support.

Well done to all those who took part in the discussion and preparation of the Power Factor document. I am extremely proud that this initiative has been taken by YALE. I now await with similar interest the findings of a further Specialist Group who are working on a single meter, multi-utility concept which is currently on trial in Kirklees Metropolitan Council. Hopes run high that, as a result of these and future planned schemes, the member and user authorities who form our Consortium, will benefit from these findings and the economies that accurate, and not estimated, consumption readings will bring, allied of course to the elimination of waste and the continued promotion of increased efficiency.



Steve P. Atherton
Director, Yorkshire Purchasing Organisation

2. Introduction to YALE

YALE is a group of Yorkshire and Lancashire Engineers formed from the Yorkshire Purchasing Organisation (YPO) Specialist Energy Panel and the Greater Manchester Association of Metropolitan District Engineers (GMADE). This report has been produced by the group on behalf of its parent members.

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3. Background to the Power factor Issue

The Power Factor issue associated with street lighting and electricity supply can be likened to the leakages associated within the water industry. Both issues represent inefficiency and waste of a valuable resource and, similarly, both have a serious impact on the modern global environmental agenda.

Local Authorities and others who meet recognised criteria and who are judged by Distribution Companies to be responsible are given Unmetered Electricity Supplies where the load and consumption is predictable and within predefined limits. It would be impractical to install meters in many of these applications which are usually for the purposes of lighting the public highway, illuminated road signs and bollards.

Typical SON Lantern

The energy used by each lamp type is defined in the Balancing & Settlement Code of Practice 520 (BSCP520). Whilst each individual piece of apparatus consumes a relatively small amount of energy, it has been estimated that there are almost seven million street lights in the UK and a further one million illuminated road signs (Source: Department of Transport). On aggregate this represents an enormous load on the nation's electrical infrastructure.

A 'Connection Agreement' is signed by the DNO and the Organisation receiving the Unmetered Electricity Supply which stipulates the terms of use. The Agreement includes a requirement to maintain the Power Factor of the electrical circuit within certain limits. This is to ensure that both the Real and Apparent Power drawn from the system is controlled and corresponds with that defined in BSCP520. If the Power Factor is not maintained and falls below the minimum requirements, there will be a proportional increase in the electrical current to supply the lamp. This will result in similar proportional increases in overall power consumption leading to wasted energy and an unnecessary increase in CO_2 emissions. Larger cables may also be required to supply the increased energy demand. The need for Power Factor correction is not unique to street

lighting supplies, the terms and conditions also apply to all sites taking a load of 100kW or more as part of their supply agreement.

Street lighting and illuminated street furniture applications use a form of discharge lighting which is extremely efficient but which requires a ballast or current limiting device in order to operate correctly. The problem with this type of equipment is that it presents an inductive (lagging) load which in turn gives a poor Power Factor. In order to overcome this problem manufacturers install a Power Factor Correction Capacitor which has leading electrical characteristics to compensate for the inductive load and therefore improves the Power Factor of the circuit.

Typical Ballast

Capacitors deteriorate with age and exposure to the environment, and are severely affected by temperature fluctuations which occur in street lighting lanterns. The capacitors provided by manufacturers tend to be inexpensive short-life units and receive little or no attention during their life. Recent research has shown that they frequently fail after only 2 to 3 years in service.

When new, the circuit will typically be designed to operate at a Power Factor of 0.85 lagging, which means the circuit is operating at 85% efficiency. Traditional street lighting circuits are expected to operate around this efficiency. However, when a capacitor fails, the Power Factor may fall as low as 0.5 at which point the circuit is then only 50% efficient.

To illustrate the effect of this, a typical side road lighting unit utilising a 70 Watt high pressure sodium discharge lamp will have a total power consumption of 90 Watts (as defined in BSCP520) and the current taken from the distribution network will be 0.44 Amps when operating at a Power Factor of 0.85 and 240 V. However, should the Power Factor fall to 0.5, the current taken will increase to 0.75 Amps which is equivalent to a 70% increase.

3. Background to the Power Factor Issue

From tests already conducted by the former Yorkshire Electricity Group, Local Authorities and subsequently the Electricity Association, the average Power Factor in street lighting installations was found to be around 0.6. If the average power consumption for a street lighting unit is taken to be 100 Watts then the current consumption is 41% higher than it needs to be. This is equivalent to estimates of up to 500,000 tonnes of uneccesary CO_2 emissions each year. This wasted energy would provide power to 350,000 homes (see Section 8 page 15). To continue to ignore this would be irresponsible.

Typical Power Factor Correction Capacitor

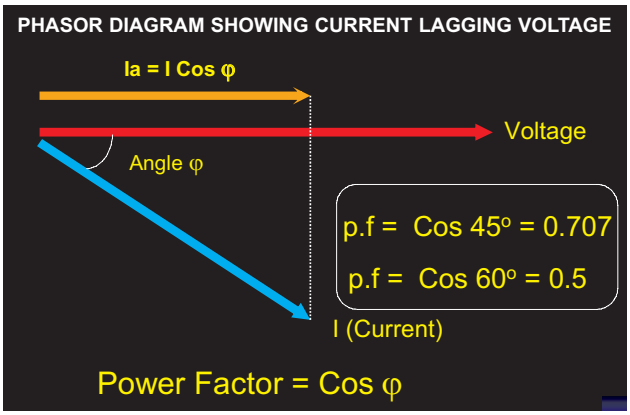
Given predicted energy supply constraints and volatile pricing issues being faced nationally, in addition to wider environmental issues such as global warming and CO_2 emissions, the issue of Power Factor in respect of public lighting applications represents a major energy efficiency issue.

4. Scale of the Problem

The Government has set a target to reduce the emission of greenhouse gases by 10% by 2010 in line with Agenda 21 agreements and the Kyoto Treaty Protocol which aims to reduce all harmful emissions into the atmosphere (see Section 11 on page 21). The recent and projected future energy demands, uncertainties in energy supply and political instability across the globe are focusing greater attention on energy usage, efficiency and waste.

Local Authority lighting is a significant load, in the hours of darkness, on low voltage supply cables and the resulting Resistance (R) leads to heat in the cables. The route of supply cables in urban and rural situations is often visible in winter conditions where the snow or ice has melted.

Many Local Authorities are choosing to use the latest development in control gear that utilises electronic circuitry and does not need traditional Power Factor Correction Capacitors. However, this only impacts on new equipment being installed which in most Local Authorities represents a relatively small proportion of their overall stock. Both Electricity Suppliers and the DNOs recognise this approach to be an improvement but are proactively looking for an option that has greater impact across the whole of the lighting stock.



There has been an increasing focus on energy efficiency and electricity system losses over recent years, highlighted by the national energy crisis. Spiralling prices have caused some Electricity Suppliers and DNOs to raise the issue of poor Power Factor and the need for recognition of the problem and improvements within the public lighting sector.

It is vital that public lighting authorities reassess Power Factor and ensure that capacitors are effectively maintained. Authorities may find audits being carried out and may need to demonstrate their approach to their Power Factor correction policy in order to avoid an increase in charges or other penalties.

5. Solutions & Options

There are two distinct problem areas to be considered. The first and most difficult to address is the **millions of street lighting units in the UK that have been installed over many years and which now most probably have poor or even non existent Power Factor correction**. National site monitoring exercises show that many capacitors are either only part working or not working at all. This situation is giving rise to a massive waste of energy resources and places an increased strain on the electrical distribution infrastructure. The second problem area is in the installation of new equipment where the specifications presently in place may be perpetuating the problem.

Combined photo cell and intelligent Power Factor correction unit

Whilst it is recognised that many Local Authorities are replacing their lighting stock with new units via planned programmes, PFIs and so on, many others cannot afford to do so and must therefore maintain their existing stock for many years to come. To deal with this situation, the following actions should be considered:

Action 1 – New Installations:

In new installations, electronic control gear offers the best solution, providing and maintaining near unity Power Factor, in addition to supporting further benefits such as longer lamp life and lower circuit Watts. The choice of lamps is also widening: compact fluorescent lamps and the new generation of ceramic metal halide lamps operating on dedicated electronic gear platforms offer low energy white light solutions. Also expected in the near future, light emitting diode (LED) powered lighting units will offer significant savings in energy and considerably longer operational life. It is also worthwhile reconsidering switch-on levels for photo cells; changing from the standard 70 lux on setting to 55 lux or even 35 lux which can effect significant savings in burning hours whilst still providing lighting when required.

Electronic Ballast

The Intelligent Management System (IMS), also known as the Central Management System (CMS), enables the lighting authority to communicate directly with individual street lamps by sending and receiving signals remotely from the office PC.

The IMS can provide the street lighting authority with much greater control over the way their street lighting is managed. The authority can choose the precise switch on and off times. Also the light output of individual lamps can be dimmed at certain times of the day dependent on road conditions. The IMS can also report on all operating variables such as the voltage, current, burning hours, consumption, lamp wattage and power factor.

Action 2 – Existing Installations:

For existing installations, planned maintenance and replacement of capacitors with more robust and longer life units should be considered owing to their relatively low cost. These could be replaced at each routine electrical testing interval (usually every 6 years). Alternatively, an intelligent Power Factor correction circuit within a photocell is now available which can correct and maintain Power Factor of any lamp type up to 150 Watts at 0.9 (90% efficiency) or higher.

In some areas, particularly on motorways, lighting is connected to dedicated distribution cables and, in these cases, bulk Power Factor correction can be used very effectively.

Typical electronic photo cell

6. Penalties & Rewards

The Ofgem Statement

'Structure of electricity distribution charges. Update document and Licence modifications. April 2004' *states:*

Power Factor

'3.35. It is important that connected parties are encouraged to operate their connections, whether demand or generation, near unity power factor to ensure efficient use of the system and maximise available capacity, avoid requirement for early capital expenditure in reinforcing the network and also to avoid increasing losses on the system. It is therefore Ofgem's view that DNOs should consider how best to reflect these costs.

3.36. Equipment exists that corrects for low power factor and therefore increases available capacity. This has the benefits of reducing losses, deferring the need for network reinforcement and improving voltage quality. Power factor correcting equipment can be installed both on customers' premises and on the network itself. Ofgem supports the use of this type of equipment because of the benefits outlined and is working with the Carbon Trust to make the case for Enhanced Capital Allowances for power factor correction equipment. It is important that DNOs' charging arrangements reflect the costs that low power factors impose on the networks and Ofgem would expect DNOs to include charges for low power factors for large customers as part of any revised charging methodology.'

From the DNO perspective, Connection Agreements state a minimum of 0.85 lagging Power Factor correction must be maintained and they are aware that some Local Authorities are failing to comply with this requirement. Actions that the DNOs might take include the imposition of financial penalties or, in extreme cases, insisting that all new supplies are metered.

The YALE group is working as a partnership between its Local Authority members, DNO and Electricity Supplier to raise awareness of the Power Factor issue and to develop a methodology to enable improvements to be made to circuit inefficiencies. By adopting the proposed positive actions outlined on pages 10 and 11 of this document, Local Authorities will demonstrate to DNOs and Electricity Suppliers that they are serious about the issues and should gain support and recognition for so doing.

- The penalties which DNOs might consider for non compliance with their Connection Agreements could include de-energisation, withdrawal of unmetered connections, enforced metered connections and financial penalties including reactive power charges and upwardly revised DUoS charges.

- The rewards for improving Power Factor will make a significant contribution to reducing environmental pollution by way of emissions and unnecessarily wasted energy. These initiatives will help Local Authorities to be "greener", Central Government to achieve its targets on CO_2 reductions, and help ensure the future of our planet.

We must all tackle this problem now.

7. The Way Forward

Local Authorities need to consider their responsibilities very carefully. Unmetered Electricity Supplies are a concession, not a right.

The environmental benefits of maintaining good Power Factor are described fully in this document and cannot be ignored. The additional cost of using electronic control gear in all new installations is less than 5% of the total cost. Replacement capacitors for existing installations will add less than £5 per installation to routine electrical testing work for most Local Authorities. This equates to an average of less than £1 per year for each lighting unit in service.

The cost of capacitor replacement can be minimised by considering the following:

- To control labour costs, the operation can be planned to take place when routine electrical tests are being done (usually every 6 years, ideally every 5 years).

- To obtain best value, the capacitors could be procured under a new framework agreement arranged by a central purchasing organisation, such as YPO, on behalf of a number of Authorities within the Pro5 alliance. The specification should be such that the unit is suitable for use in an exterior environment with a guaranteed life of 5 years.

The work required to bulk replace capacitors should be risk assessed and a suitable method statement established. This must consider the possibility that some older capacitors may contain Polychlorinated Biphenyls (PCBs) and will therefore require special handling and disposal. This material was used as the cooling and dielectric fluid in some capacitors manufactured before approximately 1983. Specialist contractors registered with the Health and Safety Executive have been identified.

Most Street Lighting Managers will already be aware of these issues and it is recommended that, as a priority, they bring these matters to the attention of the Chief, Legal and Finance Officers within their Authorities to enable appropriate funding to be put in place to ensure full compliance with their Connection Agreements.

8. Estimate of Power Wastage & CO_2 Emissions

Estimated UK energy wastage and emissions:

Total UK lighting load: 7,000,000 x 100 **= 700,000,000W** (Based on 7 million lighting units with an average load of 100W)	700,000kW or 700MW
Total current @ Power Factor of 0.85 & 240V = 700,000,000/0.85 x 240 (where 240V is average volatge in UK) **= 3,431,000A**	**Power = Amps x Voltage x Power Factor (pf)**
Total current @ Power Factor of 0.6 & 240V = 700,000,000/0.6 x 240 **= 4,861,000A**	
<u>Difference in current (Amps)</u> Increase in current due to Power Factor change: =(4,861,000 - 3,431,000) = 1,430,000A This represents a 41% increase on the 3, 431,000A required if Power factor is maintained at 0.85.	**41% increase in current**
This huge current increase affects the Apparent Power of the statement:	**Power = I^2R Losses + Load**
Total CO_2 emissions created as a result of this wasted energy (based on 430g of CO_2/kWh)	**Estimates up to 500,000 tonnes of CO_2 emissions each year**

Typical savings and costs for an individual Authority:

Using the above criteria, a typical Local Authority with 30,000 street lights would **reduce CO_2 emissions by more than 2,000 tonnes**. To achieve this, a rolling programme of capacitor replacement coincident with a 5 year electrical testing programme would require the replacement of 6,000 capacitors each year at an estimated cost of £5 or less per unit requiring an **initial investment of £30,000 per year**. (This figure would reduce, providing a programme of lantern replacement using electronic control gear is in place).

8. Estimate of Power Wastage & CO_2 Emissions

Comparison with vehicle emissions:

A band D motor car with CO_2 emissions

= 151g of CO_2 per km

(Source: http://www.vcacarfueldata.org.uk)

Average mileage 15,000km per year, therefore total emissions

= 2,265kg.

Therefore, the potential savings of up to 500,000 tonnes that could be made equate to CO_2 emissions from **200,000 vehicles.**

Comparison with domestic properties:

Average electrical usage by domestic properties in the UK

= 3,300 kWh pa.

Therefore the potential savings equates to usage by **350,000 homes.**

On a national basis the energy wasted is equivalent to the output of a small power station.

All calculations are estimates based on the information available at the time of going to print.

Units of measurement:

Term	Abbreviation	Definition
Ampere	Amp or A	A unit of electrical current
Gigawatt	GW	A unit of electrical power equal to 1,000 MW
Kilowatt	kW	A unit of electrical power equal to 1,000 Watts
Lux		A unit of illumination
Megawatt	MW	A unit of electrical power equal to 1,000 kW
Resistance	R (ohms)	Supply cables have resistance, e.g. heat in the cables
Tonne	t	A unit of mass equivalent to 1,000kg
Volt Ampere	VA	Apparent power in an alternating current (AC) circuit
Volt	V	A unit of electrical voltage

Definitions:

Apparent Power:
The product of Root Mean Squared (RMS) current and RMS voltage and is measured in Volt-Amperes (VA). It comprises both active and reactive power in alternating current circuits.

AC - Alternating Current
Average voltage in the UK is taken as 240 volts

DNO - Distribution Network Operator:
The DNO manages the installation and upkeep of the cabling, and the distribution of the electricity to the grid supply point.

CCTV - Closed Circuit Television

CO_2 - Carbon Dioxide

DUoS - Distribution Use of Systems:
A charge levied by the DNO for the transmission of electricity through its local network.

defra - Department for Environment, Food and Rural Affairs

EU - European Union

9. Definitions

Electricity Supplier:
Supplier of electrical energy via the DNO distribution network (but completely separate and independent of the DNO).

HSE - Health and Safety Executive

HFC - Hydrofluorocarbon:
Fluorocarbon emitted as a by-product of industrial manufacturing also known as a greenhouse gas.

PFC - Perfluorocarbon:
A powerful greenhouse gas emitted during the production of aluminium.

PC - Personal Computer

PCB - Polychlorinated biphenyl:
A material used as a cooling and dielectric fluid in some capacitors prior to approximately 1983 and subsequently found to be potentially carcinogenic.

PF - Power Factor:
The cosine of the angle of displacement between current and voltage in an alternating current circuit (see diagram on page 9).

Power Factor Correction Capacitor:
A device introduced into an inductive circuit in order to improve the power factor of the circuit.

PFI - Private Finance Initiative

Pro5
Five major national professional buying organisations have joined forces to support efficiency in Local Government. Pro5 has identified key markets where, by using the joint procurement expertise and extremely strong market position of its members, it will help to facilitate the migration of spend by Local Authorities onto new national contracts.

Pro5 comprises:

- Central Buying Consortium
- Eastern Shires Purchasing Organisation
- North Eastern Purchasing Organisation
- West Mercia Supplies
- Yorkshire Purchasing Organisation

PTE - Passenger Transport Executive

Real Power (Active Power):
The component of electrical power that performs work, typically measured in Watts or Kilowatts.

RMS - Root Mean Squared:
Mathematically, this refers to the square root of the average of a group of numbers. This methodology is applied to AC voltage and current owing to their sinusoidal wave form and gives a true rather than a peak value.

Unmetered Electricity Supply or Supplies:
Any supply provided by a Distribution Company terminated within a cut-out for the purpose of supplying a steady, predictable individual load of up to 500 Watts and where the provision of a meter would be impractical or excessively costly. Typical applications would include, for example, the following:

- Street lighting, signs and bollards
- CCTV cameras
- Telephone kiosks
- Bus shelters
- Advertising hoardings
- Communication kiosks and motorway transmission stations

10. Environmental Market Drivers

Kyoto Protocol

Based on international emissions (see page 21)

Government Energy White Paper

- Sets policy aspirations of 60% CO_2 savings by 2050
- Half of CO_2 savings expected from energy efficiency

Government Energy Efficiency Action Plan & Defra's 5-Year Action Plan

- Review underway of most cost-effective efficiency measures
- Changes to Building Regulations intended to raise standards in new/refurbished houses

11. References

- **Balancing & Settlement Code of Practice 520 (BSCP520) for Unmetered Supplies**
  Rules governing the operation of the balancing mechanism and the imbalance settlement process and the relationships and responsibilities of all electricity market participants.

- **Load monitoring exercise by Yorkshire Electricity Group Ltd**

- **Institute of Lighting Engineers (ILE) seminar Scarcroft, West Yorkshire 2001 (Westney)**

- **Institute of Lighting Engineers (ILE) report (Westney/Hale/Bodell)**

- **Kyoto Protocol Treaty**
  The Kyoto Protocol is a legally binding agreement under which participating industrialised countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990 (but note that, compared to the emissions levels that would be expected by 2010 without the Protocol, this target represents a 29% cut). The goal is to lower overall emissions from six greenhouse gases - carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, HFCs and PFCs - calculated as an average over the five-year period of 2008-12. National targets range from 8% reductions for the European Union and some others, 6% for Japan, 0% for Russia and a permitted increase of 10% for Iceland. The US was assigned a 7% reduction and Australia an increase of 8% but neither of these countries has signed the treaty.

- **Standard Terms for the Connection of the Customer's Unmetered Installations (CE Electric UK (YEDL)/United Utilities)**

- **Agenda 21 Agreements**
  Statutory Instrument for Unmetered Supplies

- **Ofgem Document (The Office of Gas and Electricity Markets)**
  'Structure of electricity distribution charges' clause 3.35 and 3.36

12. Member Authorities

The Yorkshire Purchasing Organisation's Street Lighting Authorities are:

Barnsley Metropolitan Borough Council

City of Bradford Metropolitan District Council

Bury Metropolitan Borough Council

Calderdale Metropolitan Borough Council

Doncaster Metropolitan Borough Council

Kirklees Metropolitan Borough Council

Knowsley Metropolitan Borough Council

Leeds City Council/Scottish & Southern PFI

North East Lincolnshire District Council

Oxfordshire County Council

Rotherham Metropolitan Borough Council

Sheffield City Council

South Yorkshire PTE

St Helens Metropolitan Borough Council

Stockport Metropolitan Borough Council

Tameside Metropolitan Borough Council

City Of Wakefield Metropolitan District Council/Amey PLC PFI

Walsall Metropolitan Borough Council/Amey PLC PFI

West Yorkshire Passenger Transport Executive

Wigan Metropolitan Borough Council

City of York Council

The Greater Manchester Association of District Engineers (GMADE) includes:

Bolton Metropolitan Borough Council

Cheshire County Council

The Impact Partnership - Rochdale Metropolitan Borough Council

Oldham Metropolitan Borough Council

Trafford Metropolitan Borough Council

Urban Vision Partnership Ltd - Salford City Council

The following are members of both the Yorkshire Purchasing Organisation Street Lighting Group and GMADE:

Bury Metropolitan Borough Council

Stockport Metropolitan Borough Council

Tameside Metropolitan Borough Council

Wigan Metropolitan Borough Council

13. More Information

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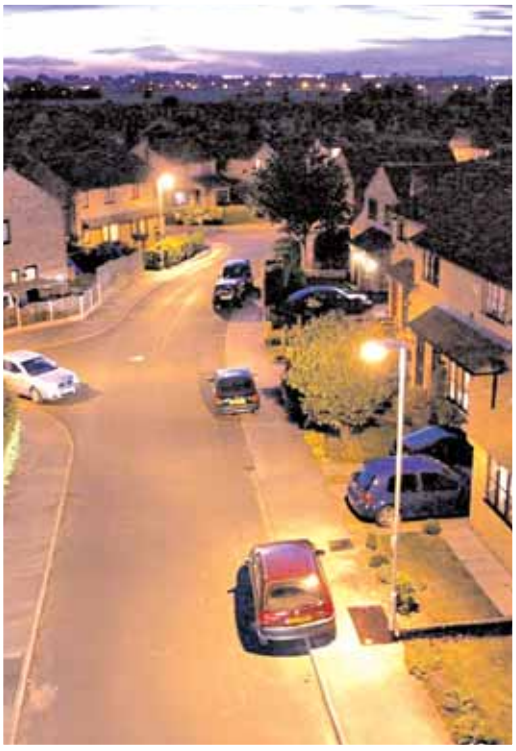
YORKSHIRE
AND
LANCASHIRE
ENGINEERS



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