

## **Key points about power supply and lighting**

- Local electricity distribution can be achieved using overhead lines, buried cables or cables attached to building frontages. All live power lines should be insulated or inaccessible for reasons of public safety.
- Primary distribution of electricity is done at high voltage, which is reduced by power transformers to the lower voltage required for local distribution and domestic use.
- Secondary level electricity distribution is normally achieved through a 'three phase' supply system, with each phase having a separate power line.
- Loads are balanced by taking off approximately the same number of tapings from each phase. Single phase spurs can supply approximately 50 houses in low income areas where the demand is relatively low.
- The objectives of street lighting in upgrading areas with minimal traffic are to facilitate pedestrian movements, recognition of obstacles and other pedestrians and to provide a degree of security.
- The principle of street lighting is to make objects appear dark against a brighter road surface.
- Single phase power supply is required.
- Fluorescent tubes are likely to be the most appropriate lamps for streets less than about 7 metres wide.
- For streets up to 3 metres wide, lanterns can be mounted on the walls of buildings 3 metres above ground level. A further option for streets up to 7 metres wide is to mount lanterns on poles 5 metres above ground level.
- For wider streets carrying substantial traffic flows, high pressure mercury lamps may be used.

## Section 4f

# **Power Supply and Lighting**

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### **Tool L1 Power supply and lighting: Objectives and options**

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#### **Objectives**

Power supply is necessary to provide increased levels of street and security lighting and to run simple household appliances. The principal benefits of domestic connections are largely related to convenience and possibly status. There is no power supply equivalent of the public standpost for water supply; connections are on an individual basis only.

#### **Mains electricity supply**

The cost of conventional power supply is influenced by the proximity of the upgrading area to existing three-phase power supply lines. Where extensions to the primary distributor system are required along with new transformers and ancillary equipment the costs become very high.

The choice of a particular system of power supply is also determined by the tariff structure of the power supply agency. Some agencies try to recover the full cost of a household connection by requiring a single connection fee to be paid, representing the total cost. Other agencies allow this connection cost to be paid off over a longer period as part of the metered user charge. With the cost of the electricity meter, a total cost connection fee normally puts a mains electricity supply out of reach of the poorest households.

#### **Fixed current supply**

There are very few possibilities to reduce costs for low income groups. A theoretical possibility is that a user group purchases power through a central meter. Distribution to the members of the user group can be on the basis of a

fixed current supply using 'everlasting fuses' which allow the automatic limiting of the current to a fixed amount. This means that only a certain load, rated at say 2 amps, can be used otherwise their supply cuts out until the load is reduced. Each member would then pay the same fixed proportion of the monthly costs. There appears to be little experience to date on this.

Another possible lower cost option is to use circuit breakers which allow a fixed current to be taken. The householders pay a fixed, known amount each month for the estimated amount of power it is possible to draw. Such a system would enable the utility to save costs on the installation, meter reading and tariff collection. There is little experience with these systems and they suffer from the inherent problem that it appears possible to by-pass the device and draw more power without paying.

### **Distribution systems**

Conventional power supply requires distribution through systems of conductors and transformers; the options include either overhead lines or underground cables. Overhead lines may be bare or insulated and either suspended between poles or attached to the face of buildings; in this latter case the lines have to be insulated. However, it does present opportunities to reduce costs; in secondary distribution systems lines and poles typically represent between 80-90% of the total costs. Whether this is a workable option depends upon local regulations and willingness to seek lower cost options for low income users.

Whilst there are a number of distinct advantages to underground cables, their cost is much higher; it was estimated that the cost was double that of overhead systems in India in 1977.

Note: material in Tools L1, L2 and L3 is adapted from the following sources:

Cotton A. P. and Franceys R. W. A. (1991) *Services for Shelter*, Chapter 8, Liverpool University Press.

Fink D. G. and Beatty H. W. (2000) *Standard Handbook for Electrical Engineers*, 14<sup>th</sup> Edition, McGraw Hill Handbooks.

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## **Tool L2 Power supply & lighting: Planning**

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### **Power demand**

In designing the distribution system, it is necessary to estimate existing demands, the likely growth in that demand and the likely peak-to-average loads. Where no other data are available, a maximum demand of 0.75-1.0 kiloWatt per household can be used for urban poor consumers; this is the 'after diversity' value, which allows for the typical nature of the demand patterns of the consumers.

Load growth should be taken care of by installing additional transformers and cutting radial secondary lines or by increasing the size of existing transformers where secondary main regulation permits. Small conductors should not be replaced by larger ones; additional transformers should be installed and parts of the existing mains transferred to the new transformers.

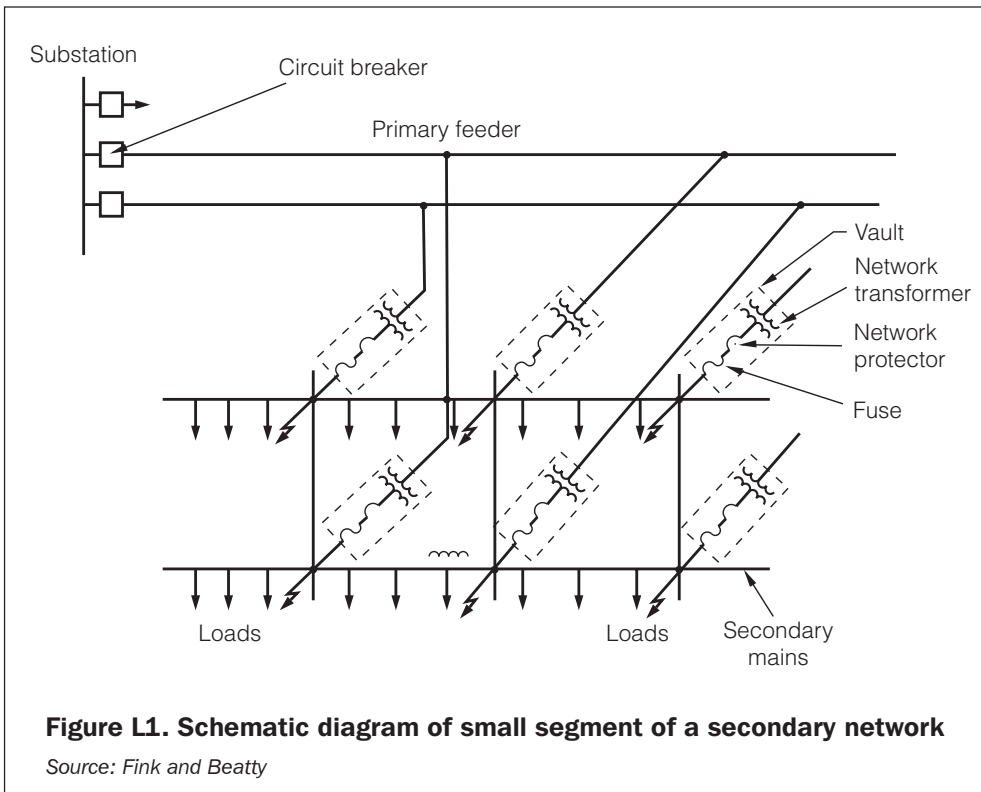
### **Primary distribution**

To generate electricity economically, power is normally taken from three coils, each surrounding one third of the rotating magnet in the generator. Power from each coil is known as a phase and to balance the load on the generator, the electrical load on each phase has to be roughly equalized. This is done most effectively by transmitting power in the three-phase form to a district sub-station from where the loads to individual consumers can be estimated and balanced. The incoming line to any locality is usually described as three-phase primary feeder comprising three overhead phase lines and in some systems a neutral or return wire. Medium voltage distribution networks operate at between 15kV and 11kV, reducing to 6.5kV in some countries. The primary feeder delivers power into the local distribution transformers which in turn feed the secondary power lines at utilisation voltage. Power connections for consumers and street lighting are taken from the secondary lines. Note that this terminology is slightly different from that used in other sectors.

### **Transformers**

The nature of electrical conductors and the losses of power incurred in transmitting energy means that the most effective way of transporting electricity is at high voltage. It is necessary to convert this 'primary' voltage down to the utilisation voltage. Transformers at grid sub-stations and district sub-stations are used to step down the voltage gradually for distribution to users.

Power utilities have their own planning criteria for the way in which primary networks feed secondary networks via transformers; these are based on minimising disruptions to supply if faults occur in one or more of the primary feeders. The local transformer usually incorporates a network protector; this is a circuit breaker which is activated in the event of reverse power-flow, faults in the transformer, or faults in the primary feeder. Figure L1 illustrates the location of transformers in relation to the primary feeders and a grid-type secondary network.

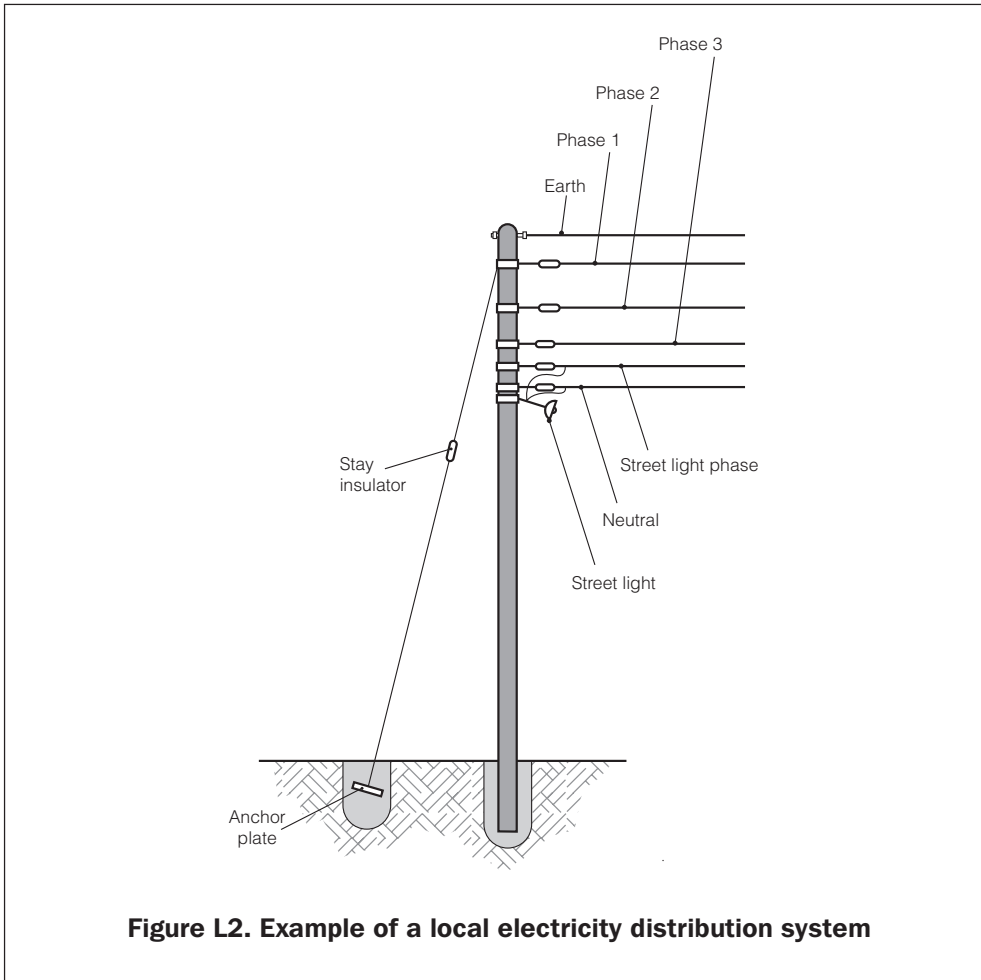


## Secondary distribution

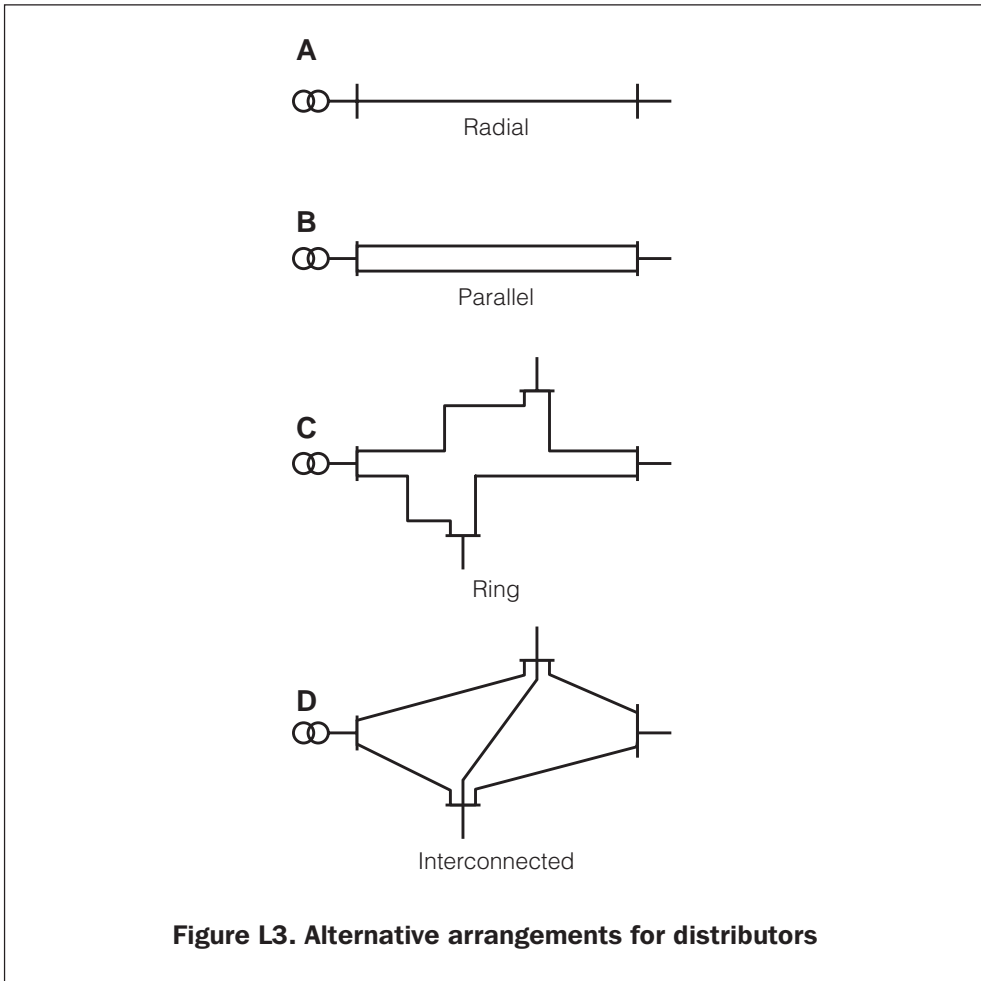
The secondary system is designed so that the loss of one transformer will not cause low voltage or a service interruption.

The low-voltage secondary distributor usually comprises three power lines representing one line for each phase plus an earth line; in some systems there may also be a line for the street lights as shown in Figure L2. It is from this distributor that the individual service connections to each household are taken. With a three-phase supply, approximately the same number of tappings

are taken off each phase to balance the load in an area. Because of the limited anticipated power demand on low-income sites it is possible to use single-phase spurs into cluster access ways serving up to 50 households.



There are various possible arrangements for distributors as illustrated in Figure L3. The radial circuit is cheapest but gives no alternative supply in case of faults and the subsequent need for repair. There is also the danger that consumers at the end of the line are more likely to suffer voltage variations as the load on the distributor varies. However, the cost of providing some form of ring or interconnected system on low-voltage systems is more costly and it is likely that radial operation will continue to predominate.



From a knowledge of the maximum power demand, load-flow calculations are made to ensure that the current in the various branches of the network does not exceed a safe working limit. Voltage and voltage drop calculations are also undertaken to ensure that the voltage at the consumer's terminals remains within acceptable limits.

The conductor size of the secondary distributor normally has to be determined from the restrictions on maximum allowable voltage drop rather than on current rating. The accepted limits for voltage drop are normally taken to be in the range of plus or minus 5 per cent or 6 per cent. However, the limits are fixed at these levels so that sophisticated electrical or electronic equipment is not damaged by excessive fluctuation in the power supply. In low-income

housing the most sensitive equipment is likely to be a television, which can operate safely with variations in voltage of plus or minus 10 per cent. As the conductor size may be dependent upon voltage drop, increasing the limits will enable smaller and cheaper conductors to be used in the cluster spurs.

Underground cables, whilst generally more expensive, have a longer life and are less likely to suffer from the type of faults associated with overhead lines, such as from storms, lightning and birds. However, any faults that develop are more difficult to locate and repair. Overhead lines require regular maintenance by skilled linesmen to inspect for defects, wear and illegal tappings whilst cables need no maintenance under normal operation.

The use of insulated lines along building frontages has the potential to reduce local distribution costs and connection costs. However, on low income housing sites where householders are being encouraged to build or upgrade their housing it is more difficult to coordinate installation when the houses have not all been built to similar standards. In slum and shanty upgrading projects where narrow and winding streets often preclude overhead lines because of lack of necessary clearance, cables fixed to walls are a suitable option. However, underground cables may be preferred because of the difficulties with continual building or upgrading.

Tool P2 describes the access requirements for power services in order to ensure that there are sufficient clearances between power lines and building lines.



## **Tool L3 Power supply & lighting: Design**

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This Tool deals principally with local power distribution and the design of street and security lighting. Detailed design of primary systems is not within the scope of this manual.

### **Power demand**

In designing the distribution system, it is necessary to estimate existing demands, the likely growth in that demand and the likely peak-to-average loads. Where no other data are available, a maximum demand of 0.75-1.0 kiloWatt per household can be used for urban poor consumers; this is the 'after diversity' value, which allows for the typical nature of the demand patterns of the consumers.

### **Transformers**

The need for a distribution transformer specifically for the area served depends upon the size of the site. Depending upon the extent of anticipated future power demand and the high cost of land on inner city or marginal sites, transformers up to 200 kVA (kiloVoltAmps) may be mounted on poles to minimize the land-take as shown in Figure L4.

The transformer is normally situated either at the centre of the site or at the entrance in order to limit the low-voltage lines to a maximum length of about 200 metres. A typical sub-station requires a plot size of 5.5 square metres to house a 1.2 square metres concrete base pad for the transformer. An access width of 3 metres is then required from a main road.

### **Power distribution losses**

Losses in power distribution systems are typically 10% of the generated output. For local distribution systems, losses occur both through transformers and along the power lines. Transformer load losses vary according to the square of the current passing through; the actual values depend on the specification of the transformer and details are provided by the manufacturer.

Line losses are primarily due to electrical resistance and are calculated as

$$\text{Line losses} = I^2R$$

where  $I$  = current

$R$  = total resistance of the cables

where the currents are those occurring under peak load conditions. A common simplifying assumption for local distribution is that the power demand is uniformly distributed, in which case the losses are the same as if the total load were concentrated at a point one-third of the distance.

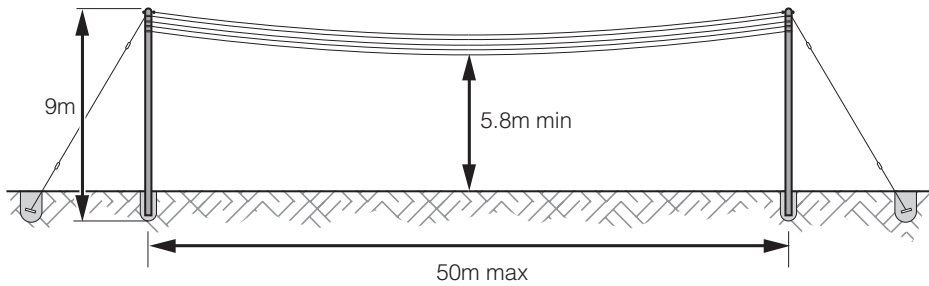
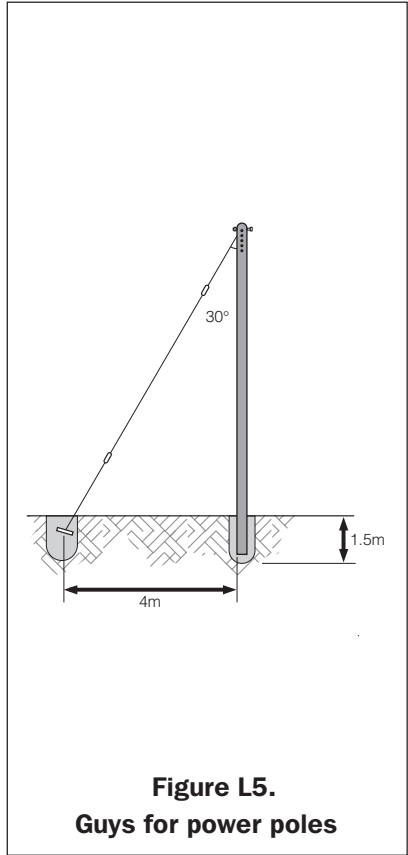
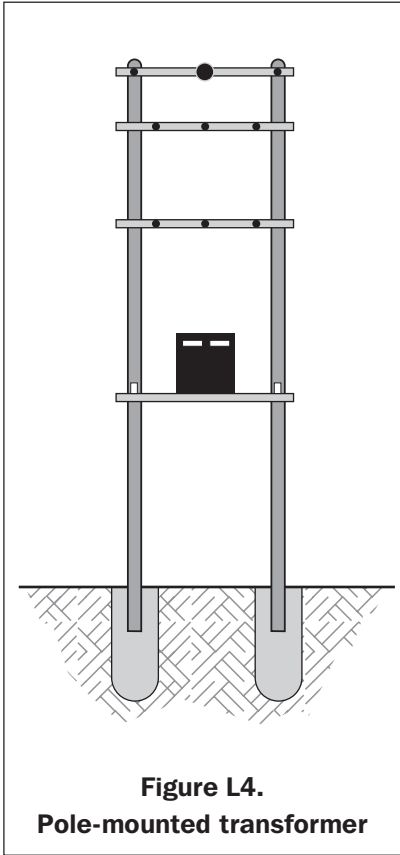
It is possible to estimate the most appropriate combination of transformers and radial secondary mains which provides satisfactory voltage regulation and costs the minimum per unit of power delivered. Standard tables for estimating power line losses are available in Electrical Engineers handbooks available locally. The procedure is as follows: use the tables to obtain a value for the voltage drop per 'amp-foot', for the proposed conductor, knowing the power factor for the supply. The actual voltage drop can then be estimated for particular assumptions about demand. For practical use, it is possible to use this method to prepare a table of estimates for the permissible length of a particular type of conductor for given limits of voltage drop and a given power demand.

In general, for neighbourhood distribution through radial secondary mains, the line length is often restricted to about 200 metres. Local power distribution engineers will often have developed their own local guidelines based on the conductor type which is most commonly used.

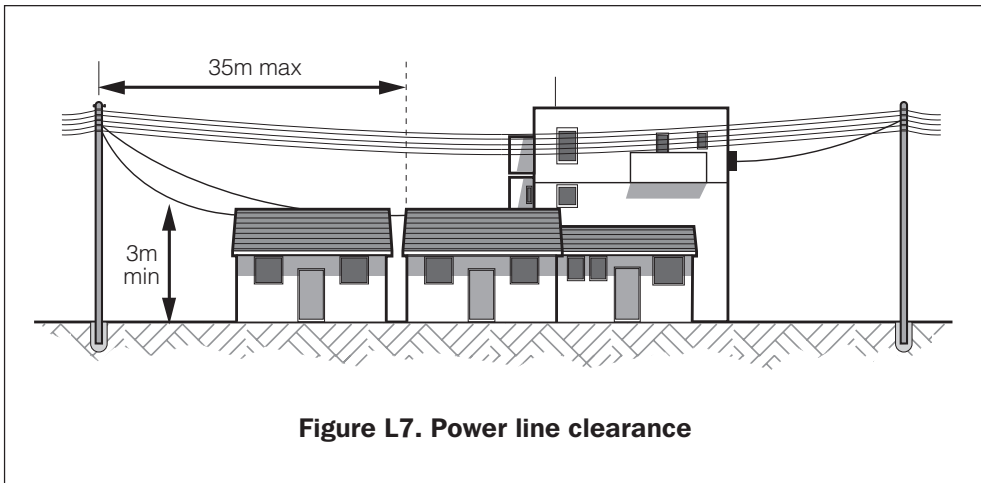
### **Overhead lines and poles**

Low voltage distributor lines require supporting power poles. Timber is commonly used, although reinforced concrete is increasing in popularity in regions where there are restrictions on the use of timber. Design involves the consideration of structural stability of the poles, and ensuring horizontal and vertical clearances through appropriate spacing of the poles. Supporting poles are normally in the range 7.6-9 metres and are embedded with one sixth of their length in the ground. Figures L5 and L6 illustrate this.

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Service connections to individual plots can create safety problems in upgrading areas where standards for building lines and set-back from the roads are not normally applied. The recommended maximum length of a connection is 25-35 metres and the spacing of the power poles may need to take this into account. The vertical drop in a service connection should never be lower than 3 metres, as shown in Figure L7.



### **Power supply for street and security lighting**

Street lighting usually requires single phase power supply, that is, one live and one neutral line. It is essential that live power lines be insulated if they are run along the walls of buildings or if they are otherwise easily accessible. Other metal parts of the lanterns such as the lamp housing and other fixtures should be earthed to ensure automatic disconnection of the supply in case they become live. Fuses or circuit breakers are normally installed so that the power supply is automatically disconnected in the event of power surging or overloading.

### **Lamps for street and security lighting**

The lamp is the source of light and converts electrical energy into radiation to which our eyes respond. The main types of lamp in use are:

- tungsten lamps (designated GLS), in which a small wire contained in a glass bulb is heated to a high temperature in a vacuum;

- fluorescent lamps (designated MCF & TL), in which ultra-violet radiation causes phosphor powder to glow inside a tube; and
- discharge lamps, in which an electric current is passed through a mixture of gases in a sealed tube. Examples are low pressure sodium, high pressure sodium, high pressure mercury (designated SOX, SON, MBF or HPL-N respectively).

Light from the lamp is usually reflected by mirrors; together with the lamp housing and some electrical fittings, the assembly is known as the luminaire. Those luminaires specifically designed for street lighting are called lanterns.

### **Lighting theory terminology**

The luminous flux represents the quantity of radiation which comes from a lamp, measured in units of Lumens.

The intensity of light emitted is measured in units of Candelas.

The illuminance of a point on the road surface which is receiving light from a lantern equals the intensity of light emitted divided by the square of the distance from the source to the point considered. Note that illuminance relates to the incident light falling on a surface. It is measured in units of Lux (which equal lumens per square metre). Illuminance forms the basis of the adopted design method and will be discussed further.

The luminance is a measure of the intensity of the light reflected from the road surface and is measured in units of Candelas per square metre. Note that luminance relates to reflected light from a surface; the relationship between light falling on a surface and the amount reflected in any direction depends upon the physical properties of the surface as well as the lantern. Luminance is now commonly used to assess lighting requirements for heavily trafficked roads.

### **Lighting levels**

For the lighting of areas used principally for pedestrian access such as narrow streets, it is important to provide a level of lighting which is sufficient to permit safe movement and recognition of obstacles and other pedestrians. Lighting also provides a degree of security, whereby potential intruders can be noticed. An additional benefit is that the attractiveness of an area is enhanced

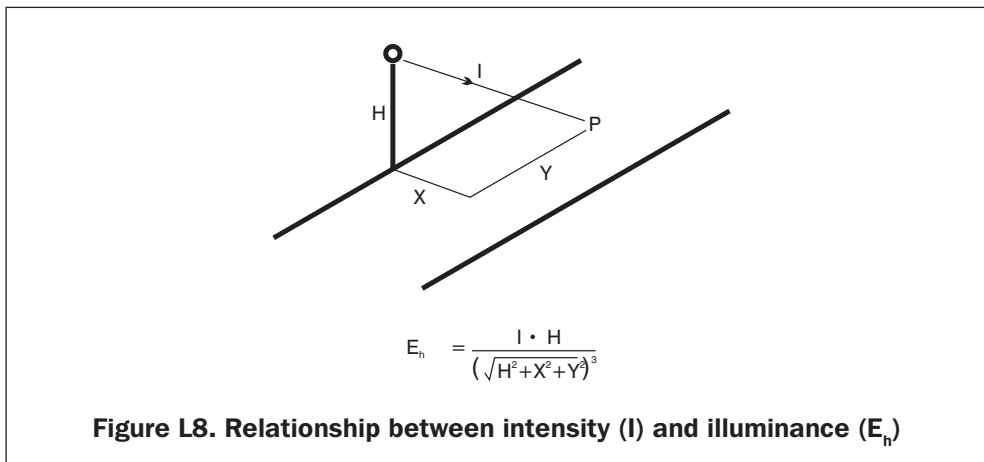
by lighting. Whilst it is desirable to provide an adequate level of lighting, the capital and operational costs increase with increasing illuminance and these must be kept to a minimum.

The following values of illuminance are recommended:	
Illuminance	Comments
0.2 lux	Minimum in order to positively detect obstacles
1 lux	Satisfactory recognition of obstacles and irregularities
5 lux	Human features are recognisable
10-20 lux	Attractive lighting

Selection of suitable lighting levels is made difficult because the above guideline figures refer to an ‘overall’ or ‘average’ level of lighting. From the definition of illuminance and Figure L8 it is clear that the illuminance at different distances from the lantern varies enormously.

It is recommended that the design criteria for areas used principally by pedestrians and a limited amount of very slow moving traffic should be to provide a minimum illuminance of 0.5 lux at any point.

Adopting this approach should mean that in most cases the ‘average’ illuminance from the lanterns is in excess of 1 lux.



## Design procedure

Having selected an appropriate level of lighting in terms of illuminance (lux), the problem is to specify:

- lantern type;
- lantern height; and
- lantern spacing;

in order to give the required illuminance in an access way of a known width.

For streets less than about 4 metres wide it will be cost effective to mount the lanterns on the walls of houses at a minimum height of 3 metres. Whilst this can also be used for streets up to 7 metres wide, better overall illumination will result from mounting the lanterns on poles which are 5 metres high. It is assumed that lanterns will be located along one side of the street only (Figure L9).

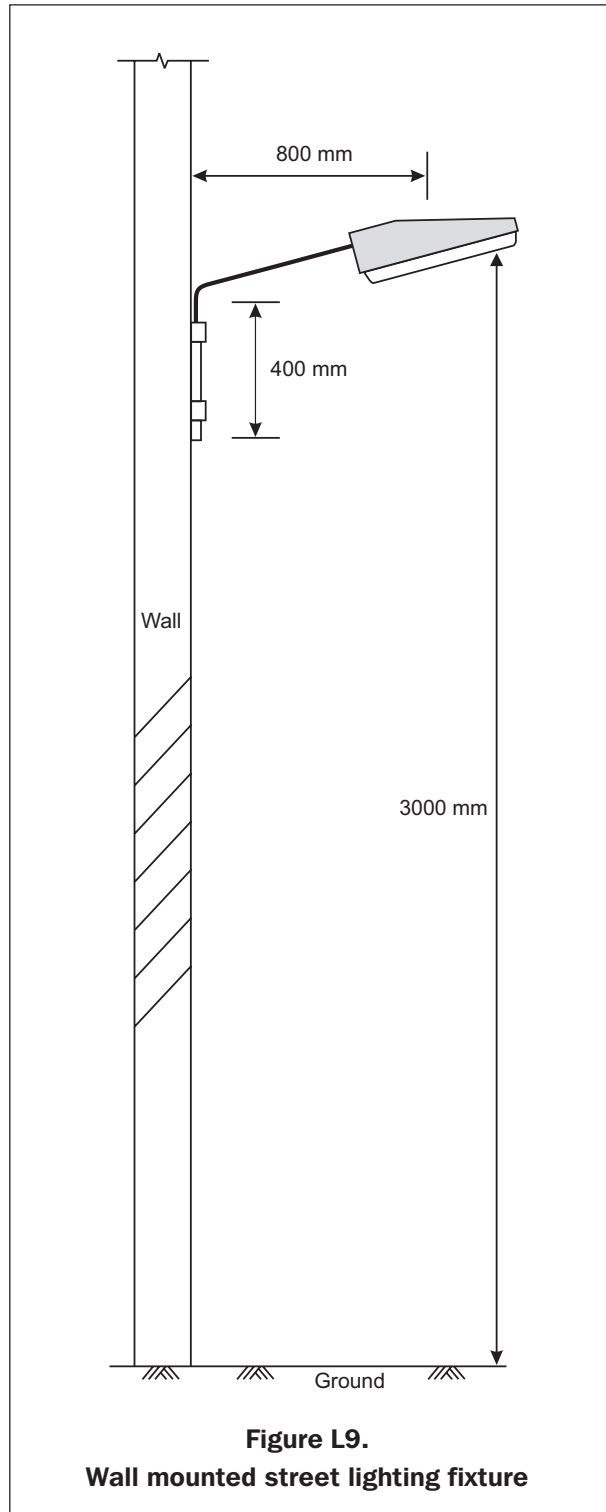
Fluorescent tubes are likely to be the most appropriate lamps for streets less than about 7 metres wide. For wider streets carrying substantial traffic flows, high pressure mercury lamps may be used in accordance with highway lighting guidelines.

<b>Street Width (m)</b>	<b>Light source</b>
2-4 metres	Two No. 20 watt fluorescent tubes wall-mounted (3 m)
4-7 metres	Two No. 40 watt fluorescent tubes wall (3 m) or pole (5 m) mounted

It is important to obtain the lamp characteristics from the manufacturer, as the following steps require the lamp intensity to be known. Approximate values are:

Two No. 20 watt fluorescent = 200 candelas  
 Two No. 40 watt fluorescent = 500 candelas

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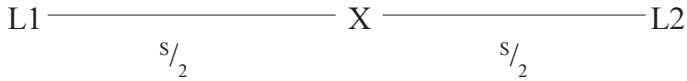


**Figure L9.**  
**Wall mounted street lighting fixture**



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The lantern spacing can be estimated if it is assumed that the minimum lighting level of 0.5 lux occurs at the mid point (X) between two consecutive lanterns (L1 and L2) separated by a distance 'S' as shown below.



Use the 'Distance Factor (DF)' from Table L1 below to estimate the required spacing (S) for a given mounting height for a lamp intensity (I) as follows.

**Step 1:** Calculate  $DF = 25/I$

**Step 2:** Read off the value of Spacing (S) corresponding to the value of DF in the table below.

Note that the maximum spacing has been assumed to be 40 metres; unless the lamps are exceptionally powerful, larger spacings will result in parts of the lighted region receiving extremely low illumination.

**Table L1. Distance Factor (DF)**

Mounting Height	3m	5m	8m
Spacing (m)	Distance Factors		
10	1.51	1.41	0.95
12	1.00	1.05	0.80
14	0.68	0.79	0.67
16	0.48	0.60	0.55
18	0.35	0.46	0.46
20	0.26	0.36	0.38
22	0.20	0.28	0.32
24	0.16	0.23	0.27
26	0.13	0.19	0.23
28	0.10	0.15	0.19
30	0.08	0.13	0.16
32	0.07	0.11	0.14
34	0.06	0.09	0.12
36	0.05	0.08	0.11
38	0.04	0.07	0.09
40	0.04	0.06	0.08

**Example** Estimate the required spacing between lanterns which are providing lighting for a street 3 metres wide. Each lantern comprises 2 No. 20 watt fluorescent tubes having a total intensity of 240 candelas which are to be wall mounted 3 metres above ground level.

**Step 1:** Calculate  $DF = 25/I = 25/240 = 0.104$

**Step 2:** Read down the '3 metre mounting height' column in the distance Factor table until  $DF = 0.10$  is reached at a spacing of 28 metres.

Therefore the lantern spacing should be 28 metres.

Note, however, that this theoretical spacing may have to be amended in practice to allow for bends in streets, incorporation of existing street lights etc.

## **Switching**

*Manual operation:* at a suitable location, for example on a power pole, a main switch is connected between supply lines and is turned on and off at the appropriate time. Up to 100 lanterns can be operated from a single switching point.

*Time switching:* these are electrically operated switches, but should also be fitted with either a reserve spring-wound time switch or a battery back-up to operate the switch in the event of power failure.

## **Fixtures**

When fixing to a wall it is important to ensure that the structure is strong enough to support the lantern and bracket; in some cases backing plates may be needed to spread the load. Where lanterns are fixed to power poles, the requirements of the power utility must be followed.

Any control gear which is not inside the lantern should be housed in strong containers which are waterproof and difficult to tamper with and are secured to the wall or pole.

Any wiring between the control gear and lantern should be protected by galvanised steel conduit in accordance with the requirements of the power utility.

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## **Tool L4 Power Supply and Lighting: Handy Tips**

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### **Security lighting: general tips**

- Low height, simple bulbs can be useful in congested slums.
- Lighting also supports home-based and local economic activity.

### **Security lighting: operation and maintenance tips**

- Community groups can replace simple bulbs or fluorescent tubes but not sodium or mercury vapour lamps.
- Lamps need regular cleaning; dirt on the surface significantly reduces the illuminance.
- Problems with power lines need to be corrected by a qualified electrician.
- Replacement of burnt-out lamps can take a long time as reporting systems are usually inadequate and require streamlining. 30-70% of all lanterns are likely to fail in any one year.
- Planned 'cyclic' replacement of bulbs/tubes may be more effective and cheaper than responding to individual lamp failures.
- Visual inspection of electrical equipment, wiring, lantern brackets and fixings needs to be carried out every three years.
- The complete electrical installation needs to be fully tested at least every five years; this covers fuses, switches, lamps, ignitors, control gear, and all wiring.
- Make sure that detailed records and drawings are kept including pole locations, type of lamp and lamp replacement dates.

