Chapter K
Energy efficiency in electrical distribution

Contents

1 Introduction

The aim of this chapter is to facilitate communication between the designers of electrical installations and the energy consumers who use them. Consumers frequently require advice on how best to reduce consumption and the amount they spend on energy.

While there are a number of factors influencing attitudes and opinions towards energy efficiency, particularly the increasing cost of energy and a growing awareness of our responsibilities towards the environment, legislation probably has the greatest impact on changing behaviour and practices. Various governments across the world are setting themselves energy saving targets and passing regulations to ensure these are met. Reducing greenhouse gas emissions is a global target set at the Kyoto Earth Summit in 1997 and was finally ratified by 169 countries in December 2006.

Under the Kyoto Protocol industrialised countries have agreed to reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990 between 2008 and 2012 (this represents a 29% reduction in terms of the emissions levels expected for 2012 prior to the Protocol). One of Europe's targets is a 20% reduction in for CO2 by 2020. Given that 27% of CO2 emissions originate from transport, 16% from residential buildings, 8% from the service sector and 49% from industry proper, up to 50% of emissions can be attributed to electricity consumption associated with residential and commercial buildings. Moreover, as the use of domestic appliances and other equipment such as ventilation and air conditioning systems increases, electricity consumption is rising at a faster rate than other forms of energy.
Against this background, the following conditions will have to be satisfied in order to achieve a 20% reduction in consumption by 2020:

- All new buildings constructed must consume 50% less energy.
- 1 in 10 existing buildings must reduce consumption by 30% each year.

As far as most countries are concerned, it is clear that 80% of the buildings which will be standing in 2020 have already been constructed. The refurbishment of existing building stock and improving energy management is vital in meeting emission reduction targets. Given that in the western world, most buildings have already undergone thermal performance upgrades such as cavity wall insulation, loft insulation and double-glazing, the only potential for further savings lies in reducing the amount of energy consumed. Action to improve the thermal and energy performance of existing buildings will almost certainly become compulsory in order to meet the targets that have been set out.

Technology exists to help promote energy efficiency on many levels, from reducing electricity consumption to managing other energy sources more efficiently. Ambitious regulatory measures may be required to ensure these technologies are adopted quickly enough to achieve the 2020 targets.

2 Energy efficiency and electricity

2.1 Une réglementation volontariste partout dans le monde

Energy saving regulations affect all buildings, both new and existing, as well as their electrical installations.

The Kyoto Protocol saw governments start to set out clear commitments in terms of quantitative targets and specific agendas for reducing CO_2 emissions.

In addition to their Kyoto obligations, many countries have set themselves fixed, long-term targets in line with the latest EEIG (European Economic Interest Group) recommendations to the UNFCCC (United Nations Framework Convention on Climate Change) regarding energy saving and based on stabilising CO_2 levels.

The European Union is setting a good example with its firm commitment, signed by all the national EU leaders in March 2007, to a 20% reduction by 2020. Known as 3x20, this agreement aims to reduce CO2 emissions by 20%, improve energy efficiency by 20% and increase the contribution made by renewable energies to 20%. Some European Countries are looking at a 50% reduction by 2050. Reaching these targets, however, wiIl require significant changes, with governments stepping up their use of regulations, legislation and standardisation.
Across the world, legislation and regulations are serving to underline stakeholder obligations and put taxation and financial structures in place.

- In the USA
  - The Energy Policy Act of 2005,
  - Construction regulations,
  - Energy regulations (10CFR434),
  - Energy management programmes for various states (10CFR420),
  - Rules for energy conservation for consumer products (10CFR430).
- In China
  - Energy conservation law,
  - Architecture law (energy efficiency and construction),
  - lRenewable energy law,
  - 1000 major energy conservation programmes for industry dans l'Union Européenne
- In the European Union
  - The EU Emission Trading Scheme
  - The Energy Performance of Building Directive
  - The Energy Using Product Directive
  - The Energy End-use Efficiency and Energy Services Directive.

2.2 see (Guide de l'installation électrique)

2.3 How to achieve energy efficiency

Whilst it is currently possible to obtain energy savings of up to 30%, this potential reduction can only really be understood in terms of the differences which exist between active and passive forms of energy efficiency.

Active and passive energy efficiency

Passive energy efficiency is achieved by such measures as reducing heat loss and using equipment which requires little energy. Active energy efficiency is achieved by putting in place an infrastructure for measuring, monitoring and controlling energy use with a view to making lasting changes.
TIt is possible to build on the savings achieved here by performing analyses and introducing more suitable remedial measures. For example, although savings of between 5% and 15% may be obtained by improving how installations are used or by optimising the equipment itself (decommissioning redundant systems, adjusting motors and heating), more significant savings can also be achieved.

- Up to 40% on energy for motors by using control and automation mechanisms to manage motorised systems,
- Up to 30% on lighting by introducing an automated management mechanism based on optimal use.

It is important to remember, however, that savings may be lost through.

- Unplanned/unmanaged downtime affecting equipment and processes
- A lack of automation/adjustment mechanisms (motors, heating)
- A failure to ensure energy saving measures are adopted at all times.

A realistic approach would be to establish the identity of energy consumers and adopt passive followed by active saving measures, before finally implementing inspection and support devices to ensure that any savings made can be sustained over the long term. This involves a four-stage process:

■ The first stage is concerned with diagnosis and primarily aims to get a better idea of where and how energy is being consumed. This requires the development of initial measures and a comparative assessment process with a view to evaluating performance, defining the main areas for improvement and estimating achievable energy saving levels. The logic behind this approach is based on the realisation that you can only improve what you can measure.

■ The next stage involves establishing basic requirements in terms of passive energy efficiency. These include:

□ Replacing existing equipment/devices with low-consumption alternatives (bulbs, motors, etc.),

□ Improving thermal insulation and ensuring that energy quality supports work in a stable environment where savings can be sustained over time.

■ The stage that follows this involves automation and active energy efficiency. Anything responsible for energy consumption must be subjected to a process of active management aimed at achieving permanent savings.

Active energy efficiency does not require highly energy-efficient devices and equipment to be already installed, as the approach can be applied to all types of equipment. Good management is essential for maximum efficiency – there is no point in having low-consumption bulbs if you are going to waste energy by leaving them switched on in empty rooms!

All things considered, energy management is the key to optimising use and eliminating waste.

■ The final stage consists of implementing basic changes, introducing automation and putting in place an infrastructure based around monitoring, support and continuous improvement. This infrastructure and the ongoing processes associated with it will underpin the pursuit of energy efficiency over future years (see **Fig. K1**).

1 Quantifying	2 Implementation of basic measures	3 Automatisation	4 Monitoring and improvement
■ Kilowatt hour meters ■ Energy quality meters	■ Low-consumption devices ■ Thermal insulation materials ■ Energy quality ■ Energy reliability	■ Building management systems ■ Lighting control systems ■ Motor control systems ■ Variable speed drives ■ Home control systems	■ Power management software ■ Remote monitoring systems

Fig. K1 : Les 4 conditions de la pérennité des économies

The key to sustainable savings

As **Figure K2** illustrates, energy savings amounting to 30% are readily achievable as things stand, although annual losses of 8% must be expected if there is neither proper support nor monitoring of key indicators. It is clear, therefore, that information is crucial to ensuring that energy savings are sustained over the long term.

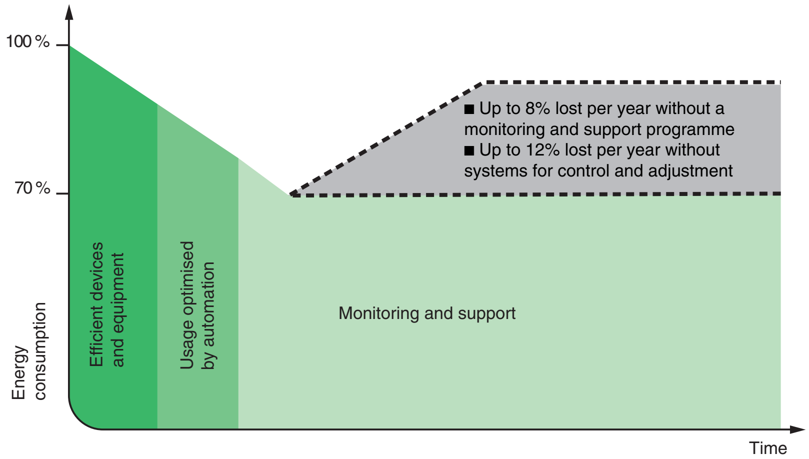


Fig. K2 : and monitoring technology ensures savings are sustained over the long term.

2 Energy efficiency and electricity

Consequently, energy monitoring and information systems are essential and must be put in place to deal with the challenges ahead.
Approaches to energy efficiency must have a proper structure if significant long-term savings are to be achieved, but only those companies with sufficient resources to actively intervene at any stage of a process will be in a position to pass the savings promised on to their customers. This is where Schneider Electric can help with its approach based on managing the life cycle of customer products (see **Fig. K3**).

Ultimately, the objectives set can only be achieved by sharing risks and developing a win-win relationship between those involved in the approach.

The reports provided by the energy monitoring or information systems can be used to formulate suitable energy efficiency projects in line with different strategies acceptable to all those involved.

- Start with a simple project involving relatively little expense and geared towards quick wins, before going on to make more significant investments (this is often the preferred business solution).
- Think in terms of how the investment for a project can and must be recouped when devising a project (this is a popular method for assessing and selecting projects). The advantage of this method is the simplicity of the analysis involved. Its disadvantage is the impossibility of tracking the full impact of a project over the long term.

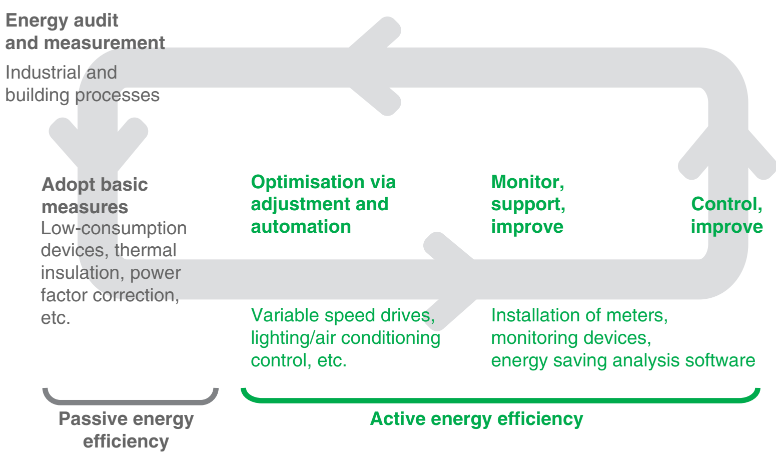


Fig. K3 : Energy efficiency solutions based on the life cycle

- Other, more complex strategies may be selected. These involve an analysis of various management parameters such as the current net value or the internal return-on-investment rate. Whilst the analysis required under these strategies demands more work, they provide a more precise indication of the overall impact of the project.

3 Diagnosis through electrical measurement

3.1 Electrical measurements

Voltage and current, two key values for understanding (almost) everything

As far as electrical measurements are concerned, voltage and current are the two values on which other values are based (power, energy, power factor, etc.).
You should have a full range of measuring devices capable of providing the specific measurements required for the application. You can significantly increase the value of your information by obtaining other data from the same measurements:
- Operating positions for devices (start/stop, open/closed, etc.)
- Number of operating hours/switching operations
- Motor load
- Battery charge
- Equipment failures
- etc.

There is no such thing as a "one-size-fits-all" solution. It is a question of finding the best compromise, in technological and financial terms, for the particular needs of the given situation, whilst remembering that measurement accuracy involves costs which have to be compared against the anticipated returns on investment.

In addition, when the operator's electrical network is expected to undergo frequent changes given the activities in which it is involved, these changes should prompt a search for immediate and significant optimisation measures.

Approaches to energy efficiency also need to take other parameters into account (temperature, light, pressure, etc.), since, assuming energy is transformed without any losses, the energy consumed by a piece of equipment may exceed the useful energy it produces. One example of this is a motor, which converts the energy it consumes into heat as well as mechanical energy.

Collating relevant electrical data for specific objectives

As well as contributing towards energy efficiency, the information gleaned from electrical data is commonly used to support a number of other objectives:
- Increasing user understanding and providing opportunities for optimising equipment and procedures
- Optimising functionality and extending the service life of equipment associated with the electrical network
- Playing a pivotal role in increasing the productivity of associated processes (industrial or even administrative/management procedures) by avoiding/reducing periods of lost productivity and guaranteeing the availability of a high-quality energy supply

c = Current measurement
S : with external sensor, D : direct measurement
v = Voltage measurement
S : avec capteur extérieur, D : mesure directe
Temperature class
Active energy accuracy class

PMD / cv / Ktt / p

Unit of measurement PM700 (Schneider Electric)

Code : **PMD/SD/K55/1**

Fig. K4 *: Identifying measuring devices in accordance with IEC 61557-12*

3.2 Adapted measuring instruments

Electronic equipment is increasingly replacing analogue equipment in electrical installations. It supports more accurate measurement of new values and is able to make these available to users at both local and remote locations.
All these various measuring devices (referred to as "PMD" for "Performance Measuring and Monitoring Device") have to meet the requirements of international standard IEC 61557-12. According to this standard, devices have a code denoting their installation options, operating temperature range and accuracy class.
As a result, it has become significantly easier to select and identify these devices (see **Fig. K4**).

A number of devices have been designed for inclusion in this category. These include Sepam overload and measuring relays, TeSys U motor controllers, NRC 12 capacitor battery controllers and Galaxy outage-free supply devices. The new Masterpact and Compact circuit breakers with integrated Micrologic measuring devices (see **Fig. K5**) also simplify matters by multiplying measurement points.

It is also now possible to broadcast measurements via digital networks. The table in **Figure K6** shows examples of measurements available via Modbus, RS485 or Ethernet.

Fig. K5 *: Compact NSX circuit breaker equipped with a Micrologic trip unit and TeSys U controller (Schneider Electric)*

	Units of measurement	MV measurement and overload relays	LV measurement and overload relays	Capacitor battery controllers	Monitoring and insulation devices
Examples	Circuit monitoring device, kilowatt hour meter	Sepam	Masterpact and Compact Micrologic circuit breakers	Varlogic	Vigilohm system
Control of energy consumption					
Energy, inst., max., min.	■	■	■	■	-
Energy, reclosing capability	■	■	■	-	-
Power factor, inst.	■	■	■	-	-
Cos φ inst.	-	-	-	■	-
Improved energy availability					
Current, inst., max., min., imbalance	■	■	■	■	-
Current, wave form capture	■	■	■	-	-
Voltage, inst., max., min., imbalance	■	■	■	■	-
Voltage, wave form capture	■	■	■	-	-
Device status	■	■	■	■	-
Fault history	■	■	■	-	-
Frequency, inst., max., min.	■	■	■	-	-
THDu, THDi	■	■	■	■	-
Improved electrical installation management					
Load temperature, thermal state of load and device	■	■	-	■	-
Insulation resistance	-	-	-	-	■

	Motor controllers	LV variable speed drives	LV soft starters	MV soft starters	Outage-free supply devices
Examples	TeSys U	ATV.1	ATS.8	Motorpact RVSS	Galaxy
Control of energy consumption					
Energy, inst., max., min.	-	■	-	■	■
Energy, reclosing capability	-	■	■	■	-
Power factor, inst.	-	-	■	■	■
Improved energy availability					
Current, inst., max., min., imbalance	■	■	■	■	■
Current, wave form capture	-	-	-	■	■
Device status	■	■	■	■	■
Fault history	■	■	■	■	-
THDu, THDi	-	■	-	-	-
Improved electrical installation management					
Load temperature, thermal state of load and device	■	■	■	■	■
Motor running hours	-	■	■	■	-
Battery follow up	-	-	-	-	■

Fig. K6 : Examples of measurements available via Modbus, RS485 or Ethernet

4 Energy saving opportunities

A number of different measures can be adopted to save energy (see **Fig. K7**).

- Reduce energy use

These measures try to achieve the same results by consuming less (e.g. installing highly energy-efficient lights which provide the same quality of light but consume less energy) or reduce energy consumption by taking care to use no more energy than is strictly necessary (e.g. another method would be to have fewer lights in a room which is too brightly lit).

- Save energy

These measures reduce costs per unit rather than reducing the total amount of energy used. For example, day-time activities could be performed at night to in order to take advantage of cheaper rates. Similarly, work could be scheduled to avoid peak hours and demand response programmes.

- Energy reliability

As well as contributing to operational efficiency by avoiding lost production, these measures avoid the energy losses associated with frequent restarts and the extra work generated when batches of products go to waste.

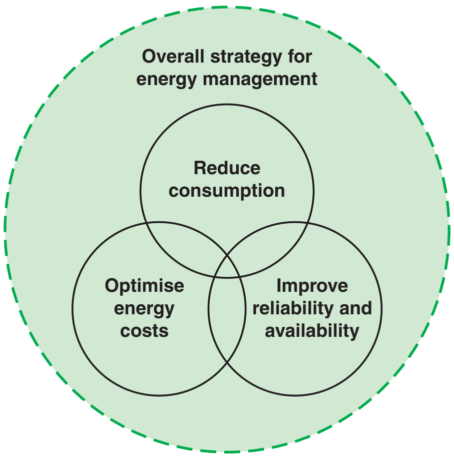


Fig. K7 : An overall strategy for energy management

In industrial applications, motors account for 60% of the energy consumed

Everyone immediately thinks of equipment for transforming energy (motors, lighting/heating devices) when considering areas where savings can be made. Less obvious, perhaps, are the potential savings offered by the various control devices and programmes associated with this type of equipment.

4.1 Motors

Motorised systems are one of the potential areas where energy savings can be made.

Those wishing to improve passive energy efficiency often consider replacing motors as a starting point. There are two reasons for this:

- To benefit from the advantages offered by new high-performance motors (see. **Fig. K8**),
- To rectify oversizing

Motors operating for long periods are obvious candidates for replacement by high-performance motors, particularly if these existing motors are old and require rewinding.

Depending on the power they generate, high-performance motors can improve operational efficiency by up to 10% compared to standard motors. Where motors have undergone rewinding, efficiency is reduced by 3% to 4% compared to the original motor.

By contrast, replacement with high-performance motors will not prove to be cost effective if the existing standard-efficiency motor – particularly if it has not undergone rewinding – experiences low or moderate levels of use (e.g. less than 30,000 hours per year). It is also important to ensure that the new motor's critical performance characteristics (such as speed) are equivalent to those of the existing motor.

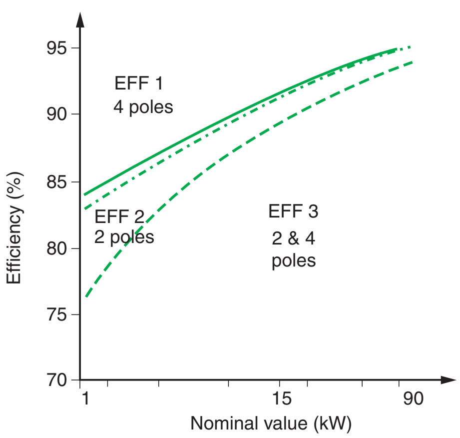


Fig. K8 : Definition of energy efficiency classes for LV motors established by the European Commission and the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP)

■ As well as being inefficient, oversized motors are more expensive to buy than correctly sized motors. Motors are at their most effective when operating at between 60% and 100% of their nominal load. Efficiency reduces rapidly at loads below 50%. In the past, designers tended to develop oversized motors in order to provide an adequate safety margin and eliminate the risk of failure, even in conditions which were highly unlikely to occur. Studies show that at least a third of motors are clearly oversized and operate at below 50% of their nominal load. The average load for a motor is around 60%.

Larger motors also tend to have lower power factors, which can lead to charges being levied for reactive power. When deciding whether to replace a motor, it is essential to take these factors, as well as the motor's remaining life cycle, into consideration. It is also important to remember that the expense of replacing an admittedly oversized motor may not be justified if its load is very small or it is only used infrequently.

All things considered, every parameter needs to be taken into account before making a decision on replacing a motor.

Other approaches are also possible, as far as motors are concerned:

■ Improving active energy efficiency by simply stopping motors when they no longer need to be running. This method may require improvements to be made in terms of automation, training or monitoring, and operator incentives may have to be offered. If an operator is not accountable for energy consumption, he/she may well forget to stop a motor at times when it is not required.

■ Monitoring and correcting all the components within the drive chains, starting with those on the larger motors capable of affecting overall efficiency. This may involve, for example, aligning shafts or couplings as required. An angular offset of 0.6 mm in a coupling can result in a power loss of as much as 8%.

■ Paying special attention to pumps and fans, because:

□ 63% of the energy used by motors is for fluid propulsion in components such as pumps and fans.

□ Flow control often uses valves, dampers and throttles, all of which cause energy to be lost by blocking ducts whilst motors are operating at full speed.

□ Effective project planning can often recoup investments in less than ten months.

Savings can be made by sizing motors correctly and using speed control and/or a variable speed drive

4.2 Speed variation

A number of technologies can be used to vary flow or pressure within a system (see Fig. **K9**). The technology chosen will depend on how the pump and fan have been designed. For example, the pump used may be a displacement or centrifugal pump, and the fan used may be a centrifugal or axial-flow fan.

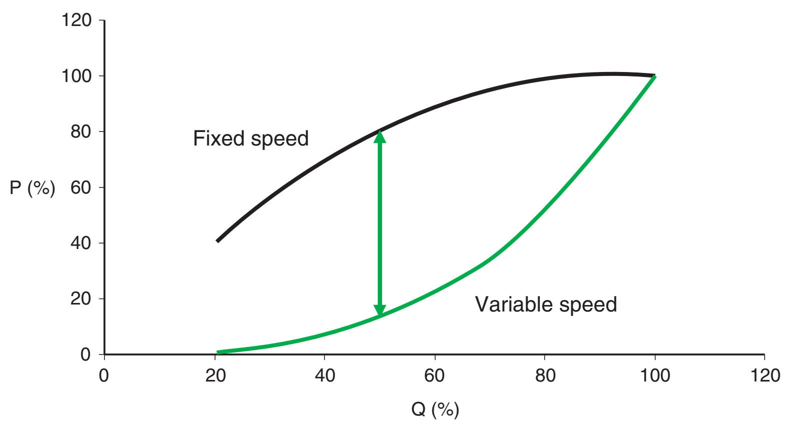


***Fig. K9** : Theoretical energy savings based on reducing fan speed by half*

Every time a fan or a pump is installed with a view to achieving specific flow or pressure levels, sizing is based on maximum demand. As a result, oversizing is the norm, and the device concerned will not operate efficiently at other speeds. In general, systematic oversizing, combined with the ineffective control methods described above, allows scope for significant energy savings to be made by using control methods aimed at reducing the pump or fan's supply current during periods of reduced demand.

Systems with fans and pumps are governed by certain correlations:

■ Flow is proportional to shaft speed, e.g. reducing speed by half reduces flow by the same amount (see **Fig. K10**).

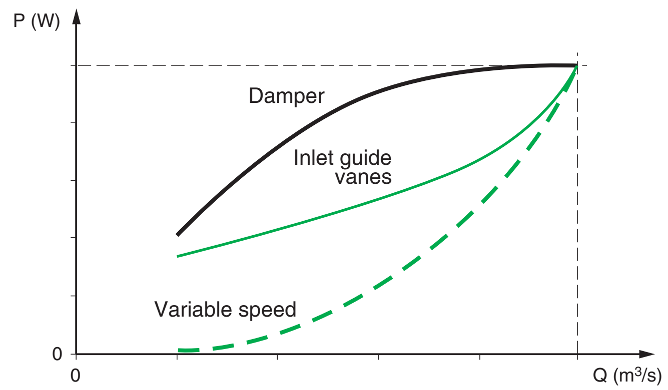


Fig. K10 : Relationship between energy and flow for different methods of fan control (damper, inlet vanes and variable speed)

■ Pressure or head is proportional to the square of the shaft speed; halving the shaft speed reduces pressure by a quarter.

■ Energy is proportional to the cube of the shaft speed.

Halving the shaft speed reduces energy consumption by an eighth and, by implication, halving the flow reduces energy consumption by an eighth.

In light of this, energy consumption can be reduced in cases where the fan or the pump does not have to generate 100% of the flow or pressure. The savings involved are significant, even where the flow is only reduced by a small amount (see **Fig. K11**). Unfortunately, the efficiency losses incurred by the various components mean that these theoretical values cannot be achieved in practice.

Technology	Disadvantage
Control of stopping and starting	This method is only effective when intermittent flow is acceptable.
Control valve: a valve is used to control flow by increasing frictional resistance at the pump's outlet.	Energy is wasted, as the flow produced by the pump is subsequently reduced by the action of the valve. In addition, pumps have an optimal operating level and increasing resistance by this method may force the pump to operate at a less efficient level (with additional energy loss) where it may be less reliable.
Bypass device: with this method, the pump turns continuously at full speed and excess fluid at the pump's outlet is channelled upstream, causing flow to be reduced without the risk of outlet pressure increasing.	The system is very inefficient, as the energy used to pump excess fluid is completely wasted.
Multiple pumps or fans: these configurations support ad hoc increases by activating extra pumps or fans, making control difficult.	There is usually a loss in efficiency, as the actual need is often somewhere between the different speeds available.
Damper: a similar technology to the control valve in systems with a pump, this reduces flow by partly obstructing the fan's outlet.	Energy is wasted, as the flow generated by the fan is subsequently reduced by the action of the damper.
Overflow valve: a similar technology to the bypass valve in systems with a pump. The fan rotates at full speed continuously and the excess gas flow is evacuated.	The system is very inefficient, as the energy used to propel the air or gas is completely wasted.
Fan with adjustable blades: the flow can be changed by adjusting the blades.	Energy is wasted, as the flow generated by the fan is subsequently reduced by the action of the blades.
Inlet guide blades: fins are used to obstruct or facilitate gas flow inside a fan, thereby determining its efficiency.	The fan does not generate excess flow, but does not operate at maximum efficiency either.

Fig. K11 : Examples of technologies which may benefit from using a variable speed drive

Using a variable speed drive (see Fig. K12), as opposed to the technologies discussed earlier, constitutes an active energy efficiency method and provides the type of variable efficiency required for optimal pump or fan operation.

Altivar 12 (< 4 kW)

Altivar 21 (< 75 kW)

Altivar 71 (< 630 kW)

Fig. K12 : Altivar drives with different power ratings

Certain scenarios favour simple solutions:

- When changing the dimensions of the pulleys enables fans or pumps to turn at their optimal speed. This solution does not afford the flexibility associated with variable speed drives, but it involves little work and could well be covered by the maintenance budget without the need for any additional investment.
- When the fan or pump can operate at full speed continuously without the control features referred to above being installed, or with these control features installed but unused (e.g. with dampers and valves fully opened). Under this arrangement, the device will operate at or near optimum efficiency.

In reality, the potential savings will depend on the model of the fan or pump used, its intrinsic efficiency, the size of the motor, annual operating hours and the cost of electricity locally. These savings can be calculated using special software or can be estimated with some accuracy by installing temporary meters and analysing the data obtained.

Speed regulation: Correctly adjusting energy consumption in line with needs

4.3. Control

The previous section showed how pumps and fans can benefit from the use of variable speed drives. Still further advantages can be enjoyed by using these in conjunction with control devices tailored to meet individual requirements.

- Control based on fixed pressure and variable flow: this type of control is often used for water distribution systems (drinking water, irrigation). It is also used to circulate fluids in cooling applications.
- Control for heating systems: in heating and cooling circuits, flow should vary with temperature.
- Control based on fixed flow and variable pressure: mainly associated with pumping applications (pressure differences caused by different levels) such as cleaning, watering, cooling and freezing installations. These require a certain amount of water, even where suction and discharge conditions vary.

The immediate advantages are:

- Improved control and greater accuracy in terms of pressure and flow values
- Significant reduction of transient effects within the electrical network and of mechanical restrictions affecting systems
- Reduced noise and vibrations, as drives support fine speed adjustments, thereby preventing equipment from operating at the resonance frequency for ducts and pipes
- Smooth starting and stopping

These in turn bring about further advantages:

- Greater reliability and extended service lives for systems
- Simpler tubing and pipe systems (by dispensing with dampers, control valves and bypass pipes)
- Reduced maintenance

The ultimate goal is to reduce energy consumption and its associated costs.

4.4. Lighting

Lighting can account for over 35% of energy consumption in buildings, depending on the types of activities carried out in them. Lighting control is one of the easiest ways to make substantial energy savings for very little investment and is one of the most common energy saving measures.

Lighting systems for commercial buildings are governed by standards, regulations and building codes. Lighting not only needs to be functional, but must also meet occupational health and safety requirements and be fit for purpose.

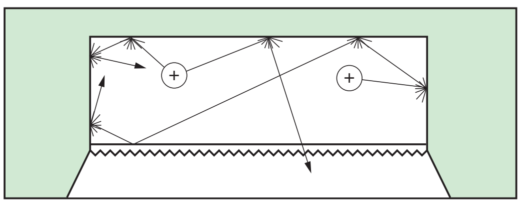
In many cases office lighting is excessive and there is considerable scope for making passive energy savings. These can be achieved by replacing inefficient luminaires, by replacing obsolete lights with high-performance/low-consumption alternatives and by installing electronic ballasts. These kinds of approach are especially appropriate in areas where lighting is required constantly or for long periods and savings cannot be achieved by simply switching lights off. The time taken to recoup investments varies from case to case, but many projects require a period of around two years.

Lights and electronic ballasts

More efficient lights may be a possibility, depending on the needs, type and age of the lighting system. For example, new fluorescent lights are now available, although ballasts also need to be replaced when lights are changed.
New types of ballast are also available, offering significant energy savings compared to the earlier electromagnetic ballasts. For example, T8 lights with electronic ballasts use between 32% and 40% less electricity than T12 lights fitted with electromagnetic ballasts.
Having said this, electronic ballasts do have a number of disadvantages compared with magnetic ballasts. Their operating frequency (between 20,000 and 60,000 Hz) can introduce harmonic noise or distortion into the electrical network and presents the risk of overheating or reducing the service life of transformers, motors and neutral lines. There is even a danger of overvoltage trips being deactivated and electronic components sustaining damage. However, these problems are mainly restricted to facilities with heavy lighting loads and a large number of electronic ballasts. Most current types of electronic ballast feature passive filtering in order to keep harmonic distortion to less than 20 percent of fundamental current, or even 5% for more sensitive facilities (hospitals, sensitive manufacturing environments, and so on).

Other types of lighting may be more appropriate, depending on the conditions involved. An assessment of lighting needs will focus on evaluating the activities performed and the required levels of illumination and colour rendering. Many existing lighting systems were designed to provide more light than required. Designing a new system to closely fit lighting needs makes it easier to calculate and ultimately achieve savings.

Apart from the issue of savings, and without forgetting the importance of complying with the relevant standards and regulations, there are other advantages associated with retrofitting lighting systems. These include lower maintenance costs, the chance to make adjustments based on needs (office areas, “walk-through” areas etc.), greater visual comfort (by eradicating the frequency beat and flickering typically associated with migraine and eye strain) and improved colour rendering.



Above: Around 70% of a fluorescent tube’s light is directed sideways and upwards.

Below: The new silver surfaces are designed to reflect the maximum amount of light downwards.

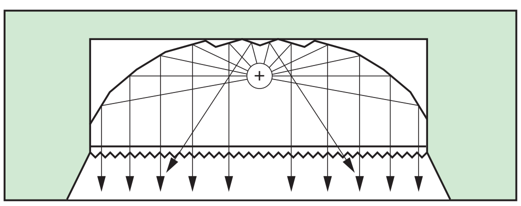


Fig. K13 : Illustration of the general operating principle for high-performance reflectors

Reflectors

A less common passive energy efficiency measure, but one which is worth considering in tandem with the use of lights fitted with ballasts, is to replace the reflectors diverting light to areas where it is needed. Advances in materials and design have resulted in better quality reflectors which can be fitted to existing lights. These reflectors intensify useful light, so that fewer lights may be required in some cases. Energy can be saved without having to compromise on lighting quality.
New, high-performance reflectors offer a spectral efficiency of over 90% (see **Fig. K13**). This means:

- Two lights can be replaced by a single light, with potential savings of 50% or more in terms of the energy costs associated with lighting.
- Existing luminaires can be retrofitted by installing mirror-type reflectors without having to adjust the distance between them. This has the advantage of simplifying the retrofitting process and reducing the work involved, with minimal changes made to the existing ceiling design.

Lighting control

The passive energy saving measures described above leave further scope for making savings. The aim of lighting control programmes is to give users the required levels of convenience and flexibility, whilst supporting active energy savings and cost reduction by switching lights off as soon as they are no longer needed. There are a number of technologies available with various degrees of sophistication, although the time taken to recoup investments is generally short at six to twelve months. A multitude of different devices are currently available too (see **Fig. K14**).

Fig. K14 : A selection of lighting control devices: timers, light sensors, movement sensors

- Timers to turn off lights after a certain period has passed. These are best used in areas where the typical time spent or period of activity is clearly defined (such as corridors).
- Occupancy/movement sensors to turn off lights when no movement has been detected for a certain period. These are particularly well suited to areas where the time spent or period of activity cannot be accurately predicted (storerooms, stairwells, etc.).
- Photoelectric cells/daylight harvesting sensors to control lights near windows. When sufficient daylight is available, lights are turned off or switched to night-light mode.
- Programmable clocks to switch lights on and off at predetermined times (shop fronts, office lights at nights and weekends)
- Dimmable lights to provide a low level of illumination (night light) at off-peak periods (e.g. a car park requiring full illumination until midnight, but where lower levels will suffice between midnight and dawn)
- Voltage regulators, ballasts or special electronic devices to optimise energy consumption for lights (fluorescent tubes, high-pressure sodium lights, etc.)
- Wireless remote control devices for simple and economical retrofitting of existing applications

These various technologies may be combined and can also be used to create a specific effect or atmosphere. For example, programmable lighting panels in meeting areas (for board meetings, presentations, conferences, etc.) have a number of different light settings which can be changed at the flick of a switch.

Centralised lighting management

Some of the lighting control systems currently available, such as those based on the KNX protocol, have the additional advantage of supporting integration into building management systems (see **Fig. K15**).
They offer greater flexibility of management and centralised monitoring, and provide more scope for energy savings by enabling lighting controls to be integrated into other systems (e.g. air conditioning). Certain systems enable energy savings of 30%, although efficiency levels will depend on the application involved and this must be chosen with some care.

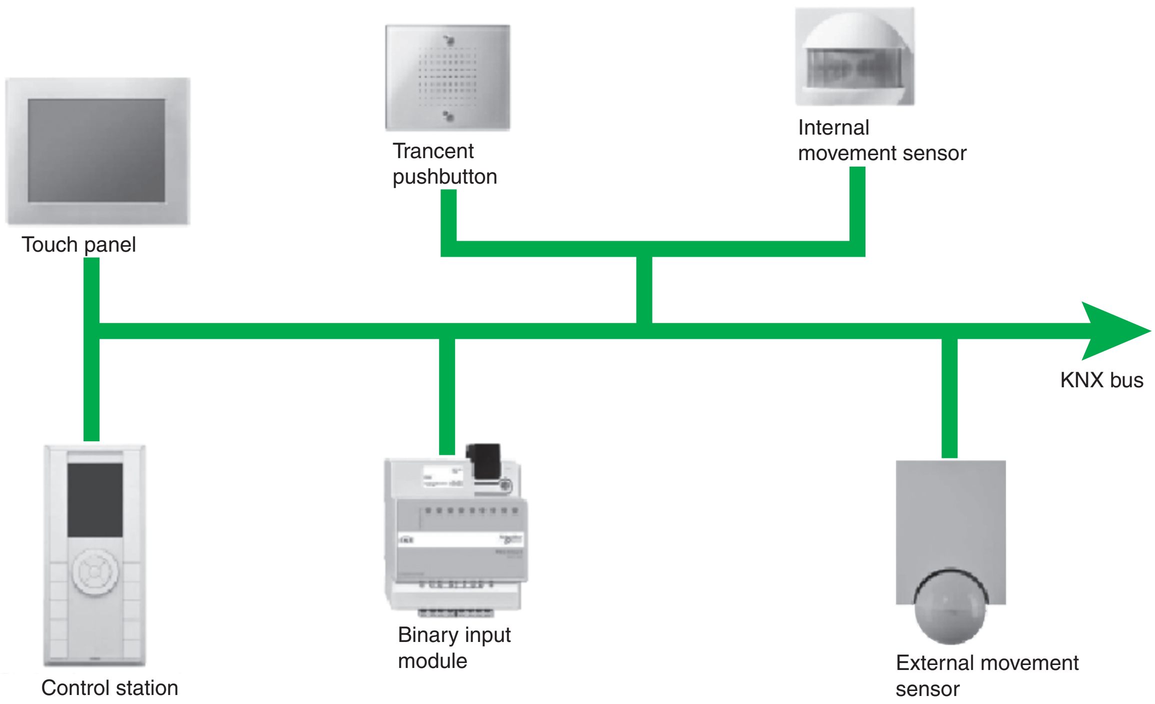


Fig. K15 : An example of links established using Schneider Electric's KNX system

If this type of system is to produce results, the design and implementation stage must begin with an audit of energy consumption and a study of the lighting system with a view to devising the best lighting solution and identifying potential reductions in terms of both costs and energy consumption. As far as this kind of technology is concerned, Schneider Electric also has solutions for offices as well as exterior lighting, car parking facilities, parks and landscaped gardens.

4.5 Power factor correction and harmonic filtering

■ If the energy distribution company imposes penalties for reactive power consumption, improving power factor correction is a typically passive energy saving measure. It takes immediate effect after implementation and does not require any changes to procedures or staff behaviour. The investment involved can be recouped in less than a year.
See Chapter L for further details.

■ Many types of equipment (variable speed drives, electronic ballasts, etc.) and computers generate harmonics within their line supply. The effects produced can sometimes be significant (transient overvoltages causing protection relays to trip, or heat and vibration potentially reducing the efficiency and service life of such equipment as capacitor banks used for power factor correction). Harmonic filtering is another typical passive energy saving measure to consider.
See Chapter M for further details.

4.6 Load management

As part of their drive towards synchronizing the consumption and production of electrical energy over the long term, energy distribution companies tailor their rates to encourage consumers to reduce their requirements during peak periods.
A number of different strategies are possible, depending on consumption levels and operating requirements: restricting demand (see **Fig. K16**), avoiding peak periods, load scheduling or even generating additional energy on site.

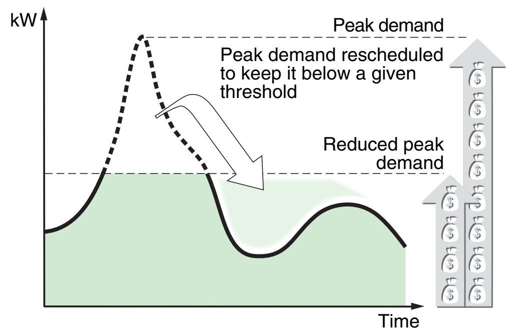


Fig. K16 : An example of a load-management strategy

■ Demand restriction
Energy distribution companies can use this solution in supply contracts containing optional or emergency (involving compulsory limits) restrictive clauses whose application is determined by the consumer (based on special rates). This management policy is typically used during the hottest or coldest months of the year when companies and private customers have very high requirements for ventilation, air conditioning and heating, and when electricity consumption exceeds normal demand considerably. Reducing consumption in this way can prove problematic in residential and service sector environments, as they may considerably inconvenience building occupants. Customers from industry may show more of an interest in this type of scheme and could benefit from contracts reducing unit costs by up to 30% if they have a high number of non-essential loads.

■ Peak demand avoidance
This method involves moving consumption peaks in line with the different rates available. The idea is to reduce bills, even if overall consumption remains the same

■ Load scheduling
This management strategy is an option for companies able to benefit from lower rates by scheduling consumption for all their processes where time of day is neither important nor critical.

■ Additional energy generation on site
The use of generating sets to supply energy improves operational flexibility by providing the energy needed to continue normal operations during periods of peak or restricted demand. An automated control system can be configured to manage this energy production in line with needs and the rates applicable at any given time. When energy supplied from outside becomes more expensive than energy generated internally, the control system automatically switches between the two.

4.7. Communication and information systems

Information systems

Whether it relates to measurements, operating statuses or rate bases, raw data can only be useful when converted into usable information and distributed on a need-to-know basis to all those involved in energy efficiency with a view to improving the expertise of all participants in the energy management process. Data must also be explained, as people can only develop the management and intervention skills integral to any effective energy saving policy if they fully understand the issues involved. Data distribution must produce actions, and these actions will have to continue if energy efficiency is to be sustained (see **Fig. K19**).
However, this cycle of operations requires an effective communication network to be in place.

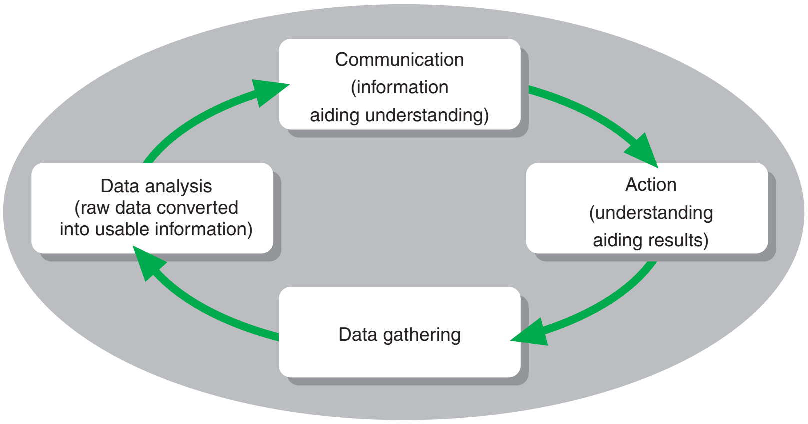


Fig. K17 : Operating cycle for data essential to energy efficiency

The information system can then be used on a daily basis by the operators at the various locations where electricity is consumed (for industrial processes, lighting, air conditioning, and so on) to achieve the energy efficiency objectives specified by company management. It can also ensure these same locations make a positive contribution to company operations (in terms of product volumes, conditions for supermarket shoppers, temperatures in cold rooms, etc.).

Monitoring systems

■ For quick audits which can be performed on an ongoing basis.
Encouraging familiarity with data and distributing it can help keep everything up to date, but electrical networks develop rapidly and are permanently raising questions about their ability to cope with such new developments.
With this in mind, a system for monitoring the transfer and consumption of energy is able to provide all the information needed to carry out a full audit of the site. As well as electricity, this audit would cover water, air, gas and steam.
Measurements, comparative analyses and standardised energy consumption data can be used to determine the efficiency of processes and industrial installations.
■ For rapid, informed decision making
Suitable action plans can be implemented. These include control and automation systems for lighting and buildings, variable speed drives, process automation, etc. Recording information on effective equipment use makes it possible to determine accurately the available capacity on the network or a transformer and to establish how and when maintenance work should be performed (ensuring measures are taken neither too soon nor too late).

Communication networks

Information and monitoring systems are synonymous with both intranet and Internet communication networks, with exchanges taking place within computer architectures designed on a user-specific basis.

■ Intranet
For the most part, data exchange in the industrial sector uses Web technologies permanently installed on the company's communications network, typically an intranet network for the sole use of the operator.
As far as industrial data exchange between systems connected via a physical transmission link, such as RS485 and modem (GSM, radio, etc.), is concerned, the Modbus protocol is very widely used with metering and protection devices for electrical networks. Initially created by Schneider Electric, this is now a standard protocol.
In practice, electrical data is recorded on industrial Web servers installed in enclosures. The popular TCP/IP standard protocol is used for transmitting this data in order to reduce the ongoing maintenance costs associated with any computer network. This same principle is used by Schneider Electric to communicate data associated with promoting energy efficiency. No additional software is needed – a PC with an Internet browser is all that is required. The fact that enclosures are autonomous removes the need for an additional computer system. As such, all energy efficiency data is recorded and can be communicated in the usual manner via intranet networks, GSM, fixed telephony, etc
■ Internet
Remote monitoring and control improve data availability and accessibility, whilst offering greater flexibility in terms of servicing. Figure K18 shows a diagram of this type of installation. Connection to a server and a standard Web browser makes it much easier to use data and export it to Microsoft Excel™ spreadsheets for the purpose of tracing power curves in real time.

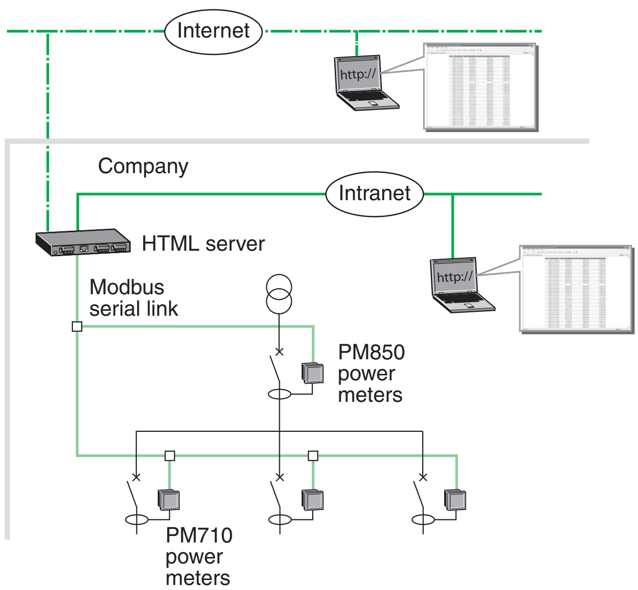


Fig. K18 : Example of an intranet information network protected by a server (EGX400 – Schneider Electric) and monitored from the Internet network

■ Architectures
Historically and for many years, monitoring and control systems were centralised and based on SCADA automation systems (Supervisory Control And Data Acquisition).
These days, a distinction is made between three architecture levels (see **Fig. 19** on the next page).
□ Level 1 architecture
Thanks to the new capabilities associated with Web technology, recent times have witnessed the development of a new concept for intelligent equipment. This equipment can be used at a basic level within the range of monitoring systems, offering access to information on electricity throughout the site. Internet access can also be arranged for all services outside the site.

□ Level 2 architecture

This system has been specifically designed for electricians and adapted to meet the demands of electrical networks.

This architecture is based on a centralised monitoring system designed to satisfy all the monitoring requirements for the electrical network. As might be expected, installation and maintenance work requires less expertise than for Level 3, since all the electrical distribution devices are already contained in a specialised library. In addition, acquisition costs can be kept to a minimum, as there are few requirements in terms of system integration.

Level 2 and Level 3 can be used side by side at certain sites.

□ Level 3 architecture

Investment in this type of system is usually restricted to top-of-the-range facilities consuming large amounts of energy or using equipment which is highly sensitive to variations in energy quality and has high demands in terms of electricity availability. To ensure these high demands for availability are met, the system often requires responsibility to be taken for installation components as soon as the first fault occurs. This should be done in a transparent manner (any impact should be clear). In view of the substantial front-end costs, the expertise required to implement the system correctly and the update costs generated as the network develops, potential investors may be deterred and they may require highly detailed prior analyses to be conducted.

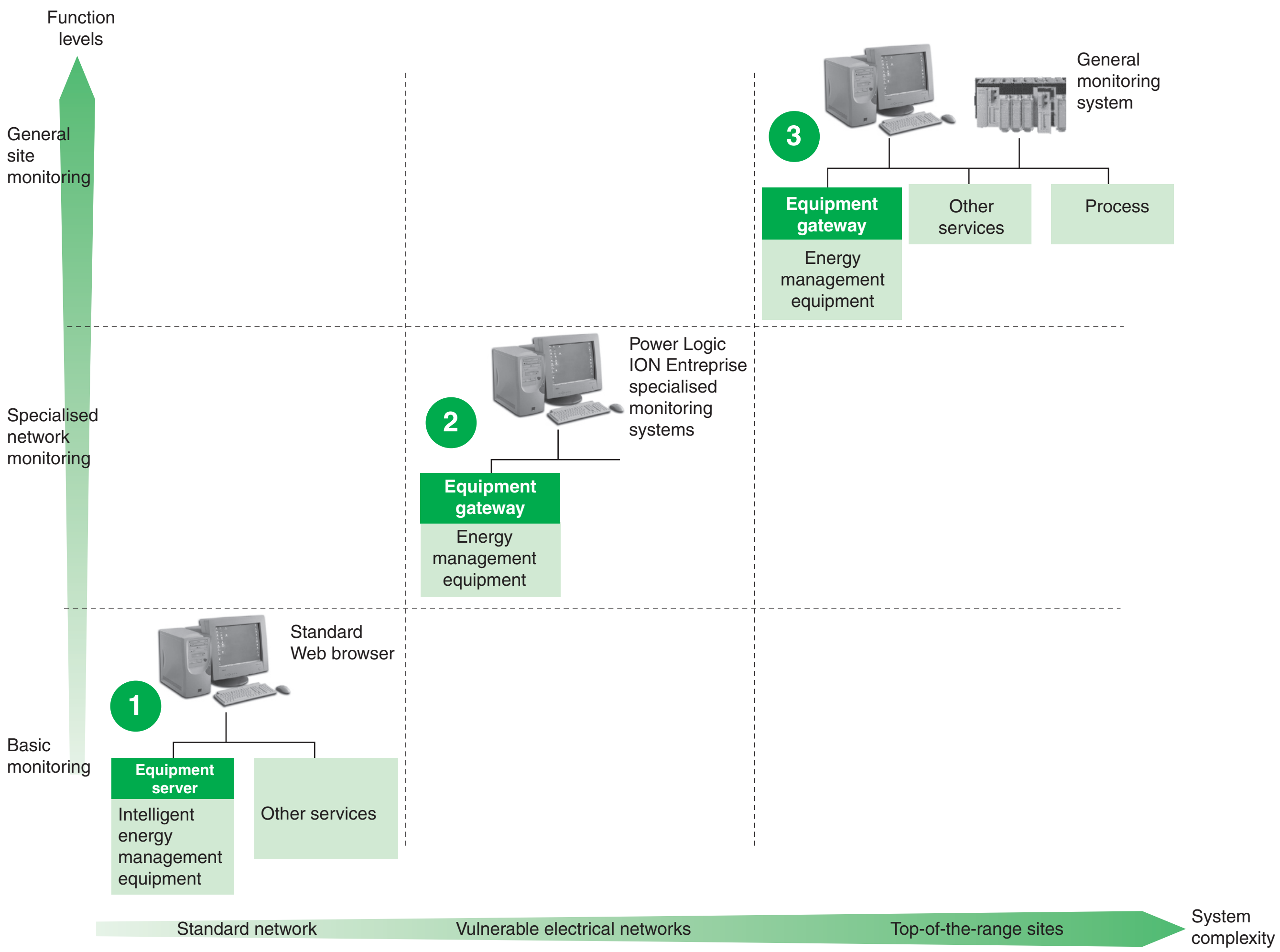


Fig. K19 : Layout of a monitoring system

4.8 Designing information and monitoring systems

In reality, systems for monitoring and energy control are physically very similar and overlap with the electrical distribution architecture whose layout they often replicate. The arrangements shown in **Figure K20** to **Figure K24** represent possible examples and reflect the requirements typically associated with the distribution involved (in terms of feeder numbers, the amount and quality of energy required, digital networks, management mode, etc.). They help to visualise and explain all the various services which can be used to promote energy efficiency.

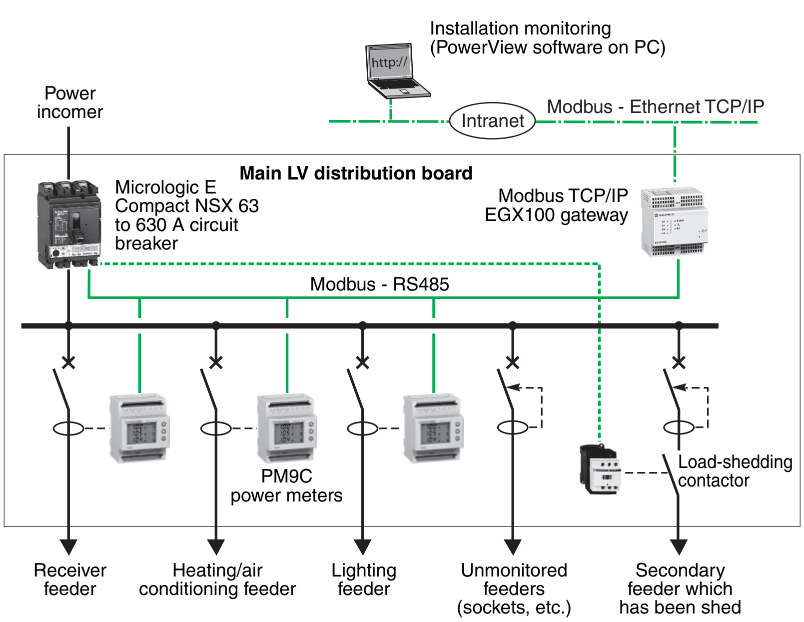


Fig. K20 : Monitoring architecture for a small site which only supports sub-metering

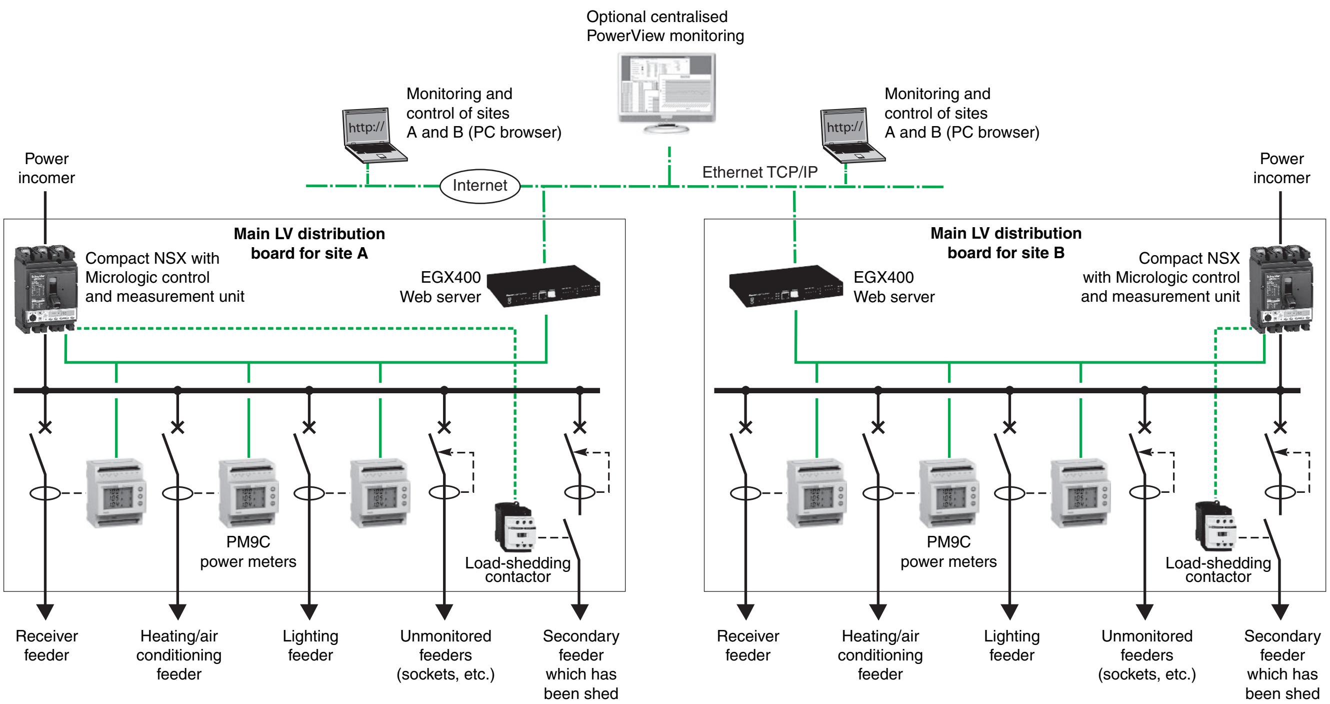


Fig. K21 : Monitoring and control architecture for a company with several small sites

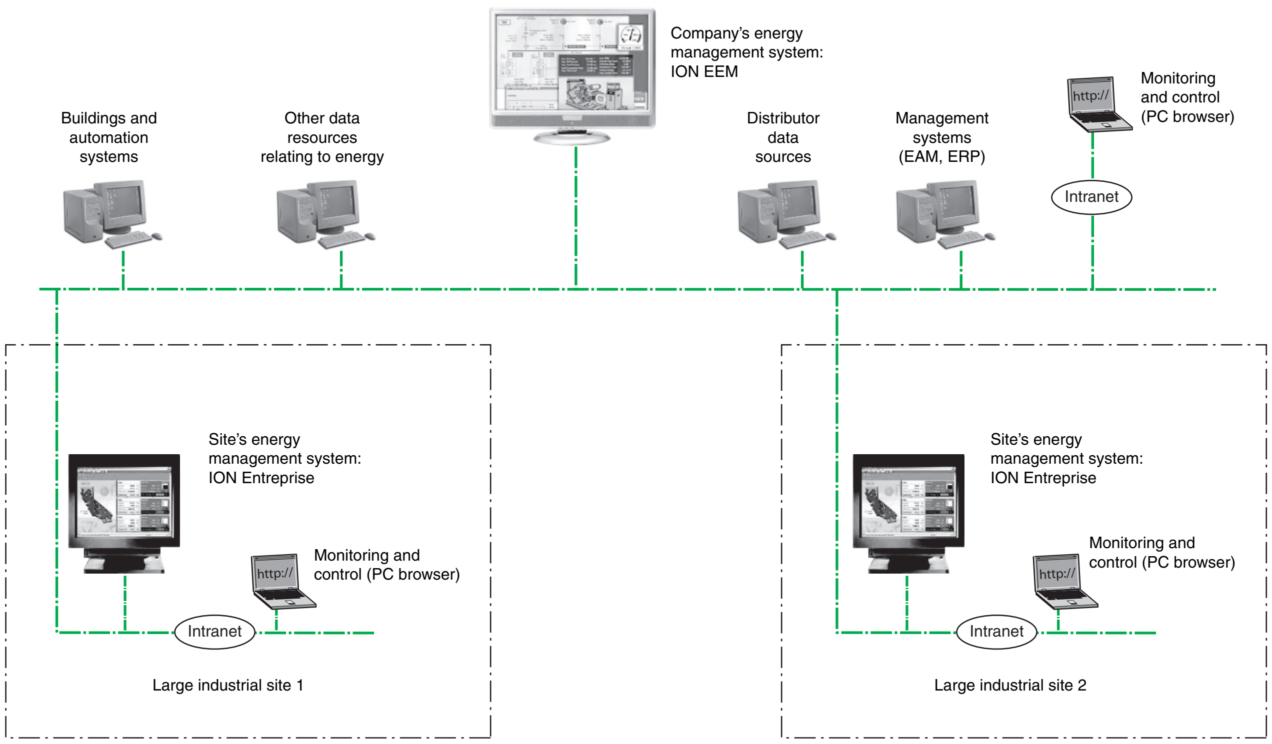


Fig. K22 : Architecture for large multiple-site arrangements

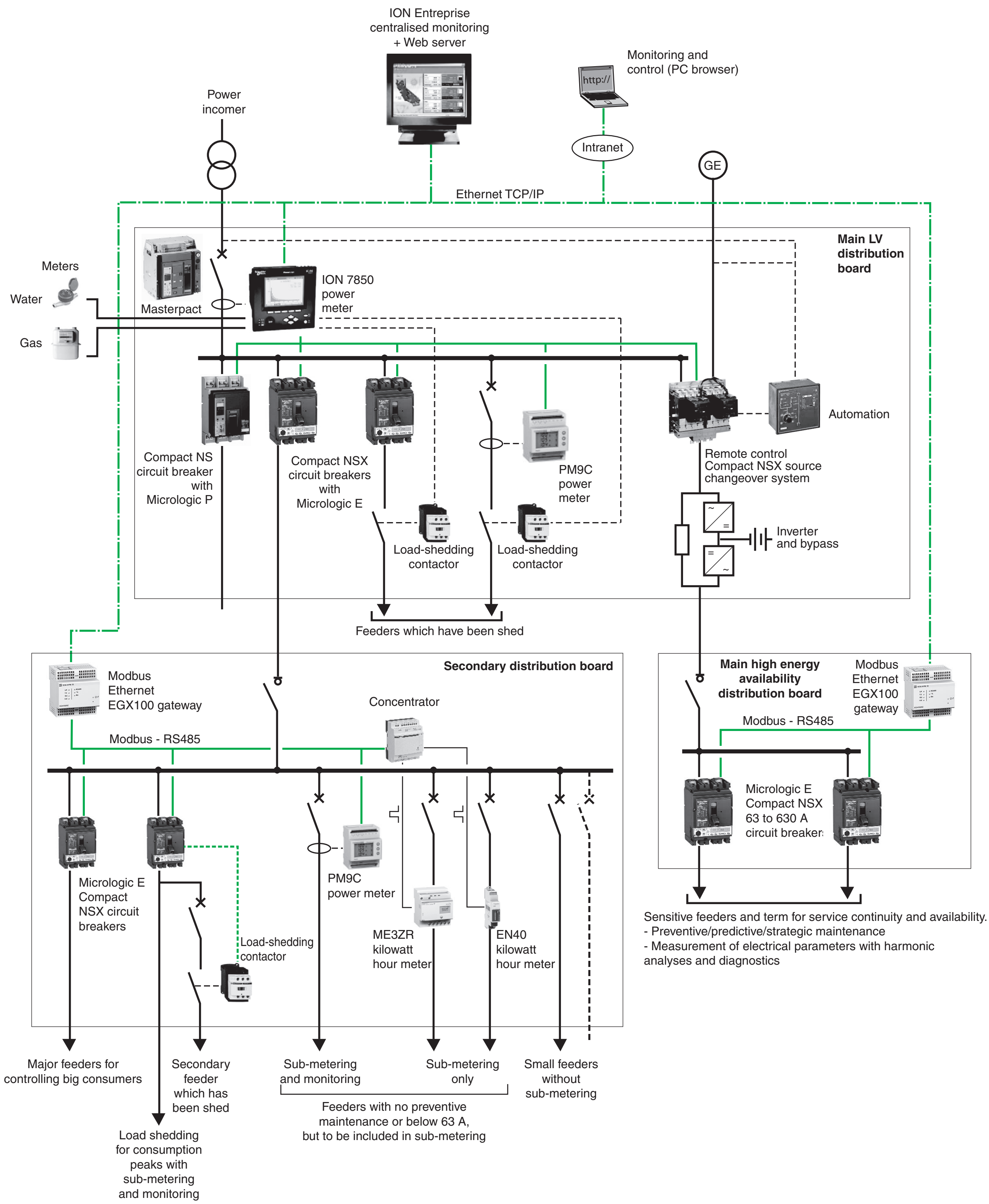


Fig. K23 : Monitoring and control architecture for a large, sensitive industrial site

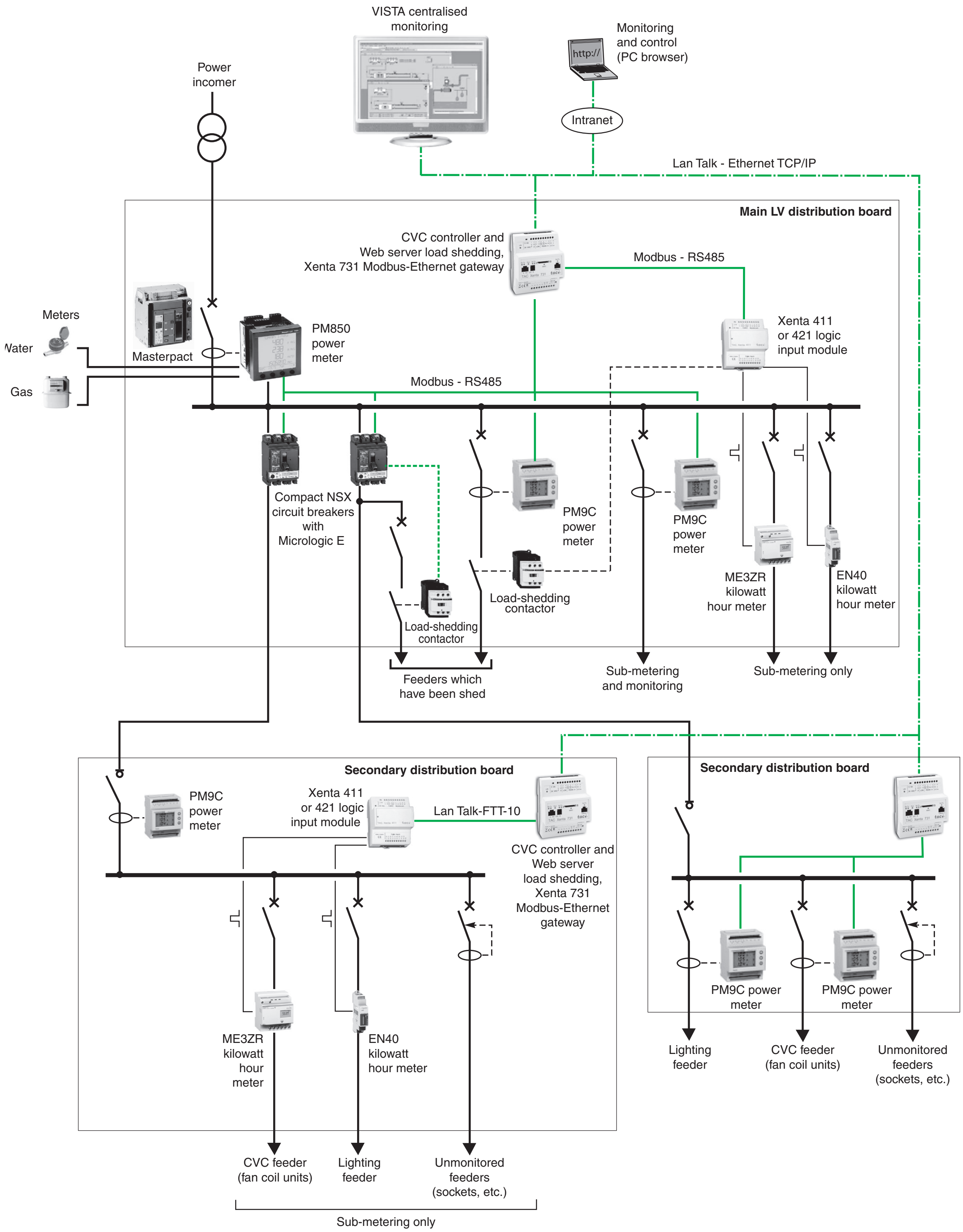


Fig. K24 : Architecture for a large service-industry site

In addition, these diagrams make it clear that the choice of components is determined by the choice of architecture (for example, the sensors must be right for the digital bus). The reverse also applies, however, since the initial choice of architecture may be affected by a technological/economic assessment of component installation and the results sought. In fact, the cost (in terms of purchase and installation) of these components, which sometimes have the same name but different characteristics, may vary widely and produce very variable results:

- A measuring device can measure one or more parameters with or without using calculations (energy, power, cos φ).
- Replacing a standard circuit breaker with a circuit breaker containing an electronic control unit can provide a great deal of information on a digital bus (effective and instantaneous measurements of currents, phase-to-neutral and phase-to-phase voltages, imbalances of phase currents and phase-to-phase voltages, frequency, total or phase-specific active and reactive power, etc.).

When designing these systems, therefore, it is very important to define objectives for energy efficiency and be familiar with all the technological solutions, including their respective advantages, disadvantages and any restrictions affecting their application (see **Fig. K27**).

To cover all the various scenarios, it may be necessary to search through various hardware catalogues or simply consult a manufacturer offering a wide range of electrical distribution equipment and information systems. Certain manufacturers, including Schneider Electric, offer advisory and research services to assist those looking to select and implement all these various pieces of equipment.

	Energy savings	Cost optimisation	Availability and reliability
Variable speed drives	● ● ●	●	●
High-performance motors and transformers	● ● ●		
Supply for MV motors	● ● ●		
Power factor correction	●	● ● ●	
Harmonics management	●	● ●	●
Circuit configuration			● ● ●
Auxiliary generators		● ●	● ● ●
Outage-free supply devices (see page N11)			● ● ●
Smooth starting	●	●	● ● ●
iMCC		● ●	● ●
Architecture based on intelligent equipment Level 1	● ●	●	
Specialised, centralised architecture for electricians Level 2	● ● ●	● ●	●
General/conventional, centralised architecture Level 3	●	● ●	● ● ●

Fig. K27 : Solutions chart

5 How to evaluate energy savings

One of the main obstacles facing those interested in devising and implementing energy efficiency projects is the lack of reliable financial data to provide a convincing business case. The higher the investment, the greater the need for credible proof of the proposed advantages. As such, it is very important to have reliable methods for quantifying results when investing in energy efficiency.

The information provided in this chapter is taken from Volume 1 of the IPMVP guide published by EVO (see www.evo-world.org)

5.1 IPMVP and EVO procedures

To cater for this need, EVO (Efficiency Evaluation Organization), the body responsible for evaluating performance, has published the IPMVP (International Performance Measurement and Verification Protocol). This guide describes the procedures used when measuring, calculating and documenting the savings achieved as a result of various energy efficiency projects. So far, EVO has published three volumes of the IPMVP, the first of which, “Concepts and Options for Determining Energy and Water Savings”, outlines methods of varying cost and accuracy for establishing total savings made or those made solely in terms of energy efficiency. Schneider Electric uses this document when putting together energy efficiency projects.

IPMVP principles and features

Before implementing the energy efficiency solution, a study based on IPMVP principles should be carried out over a specific period in order to define the relationship which exists between energy use and operating conditions. During this period, reference values are defined by taking direct measurements or by simply studying the energy bills for the site.
After implementation, this reference data is used to estimate the amount of energy, referred to as “adjusted-baseline energy”, which would have been consumed had the solution not been implemented. The energy saved is the difference between this “adjusted-baseline energy” and the energy which was actually measured.

If a verification and measurement plan is put together as part of an IPMVP programme, it needs to be:

- Accurate

Verification and measurement reports should be as accurate as possible for the budget available. The costs involved in verification and measurement should normally be comparatively low in terms of the anticipated savings.

- Complete

The study of energy savings should reflect the full impact of the project.

- Conservative

Where doubts exist in terms of results, verification and measurement procedures should underestimate the savings being considered.

- Consistent

The energy efficiency report should cover the following factors in a consistent manner:

  - The various types of energy efficiency project
  - The various types of experts involved in each project
  - The various periods involved in each project
  - The energy efficiency projects and the new energy supply projects

- Relevant

Identifying savings must involve measuring performance parameters which are relevant or less well known, with estimates being made for less critical or more predictable parameters.

- Transparent

All the measurements involved in the verification and measurement plan must be presented in a clear and detailed manner.

IPMVP options

Four study levels or “options” have been defined in line with the objectives assigned to this energy efficiency approach:

- Retrofitting isolation systems with measurements of all key parameters = Option A
- Retrofitting isolation systems with measurements of all parameters = Option B
- Whole facility = Option C
- Calibrated simulation = Option D

Figure 28 sets out these options in a table. The algorithm in **Figure 29** shows the process of selecting options for a project.

	Option A	Option B	Option C	Option D
Financial objective	Retrofit isolation systems: key parameter measurement	Retrofit isolation systems: all parameter measurement	Whole facility	Calibrated simulation
Description	Savings are calculated using data from the main performance parameter(s) defining energy consumption for the system involved in the energy efficiency solution. Estimates are used for parameters not chosen for actual measurements.	Savings are calculated using actual energy consumption data for the system involved in the energy efficiency solution.	Savings are established using actual energy consumption data for the facility or a section of it. Data for energy use within the facility as a whole is gathered on an ongoing basis throughout the reporting period.	Savings are established by simulating energy consumption for the facility or a section of it. There must be evidence that the simulation procedures are providing an adequate model of the facility’s actual energy performance.
Savings calculation	An engineering calculation is performed for the energy consumed during the baseline period and the reporting period based on: ■ Ongoing or short-term measurements of the main performance parameter(s), ■ And estimated values.	Ongoing or short-term measurements of the energy consumed during the baseline period and the reporting period	An analysis of data on the energy consumed during the baseline period and the reporting period for the whole facility. Routine adjustments are required, using techniques such as simple comparison or regression analysis.	Energy use simulation, calibrated with hourly or monthly utility billing data
When to use option	On the one hand, the results obtained using this option are rather equivocal given that some parameters are estimated. Having said this, it is a much less expensive method than Option B.	Option B is more expensive than Option A, as all parameters are measured. It is the better option, however, for customers who require a high level of accuracy.	For complex energy management programmes affecting many systems within a facility, Option C supports savings and helps to simplify the processes involved.	Option D is only used when there is no baseline data available. This may be the case where a site did not have a meter before the solution was implemented or where acquiring baseline data would involve too much time or expense.

Fig. K28 : Summary of IPMVP options

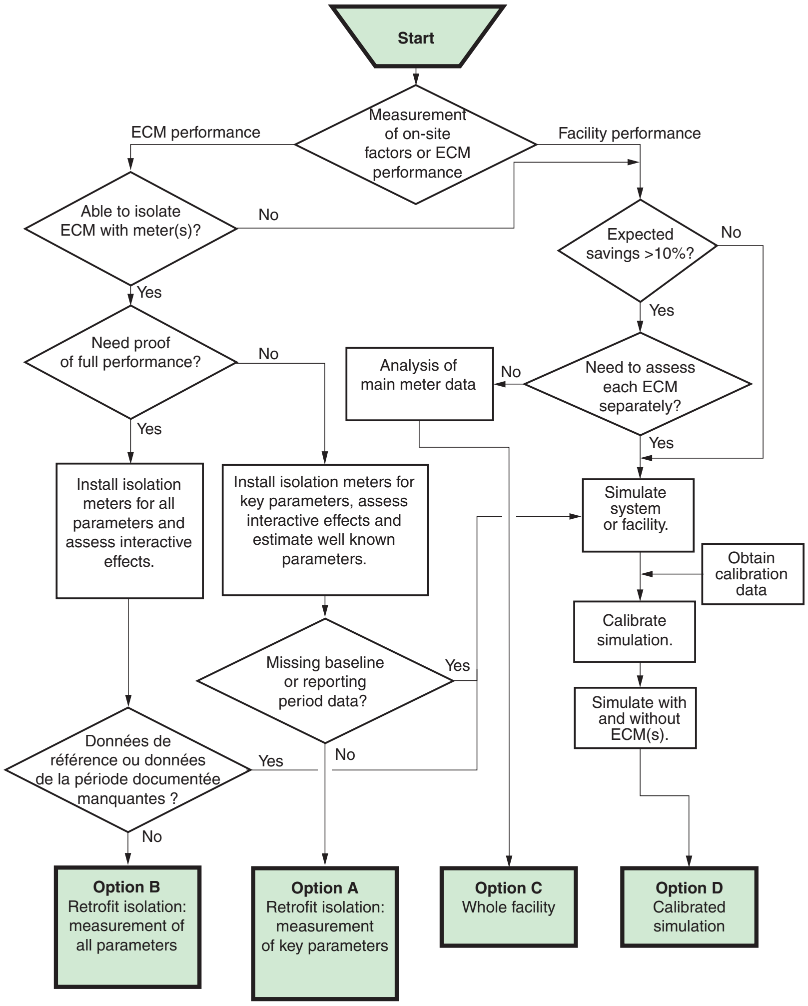


Fig. K29 : Process for selecting an IPMVP option for a project

5.2. Achieving sustainable performance

Once the energy audits have been completed, the energy saving measures have been implemented and the savings have been quantified, it is essential to follow the procedures below to ensure performance can be sustained over time. Performance tends to deteriorate if there is no continuous improvement cycle in place (see **Fig. K30**).

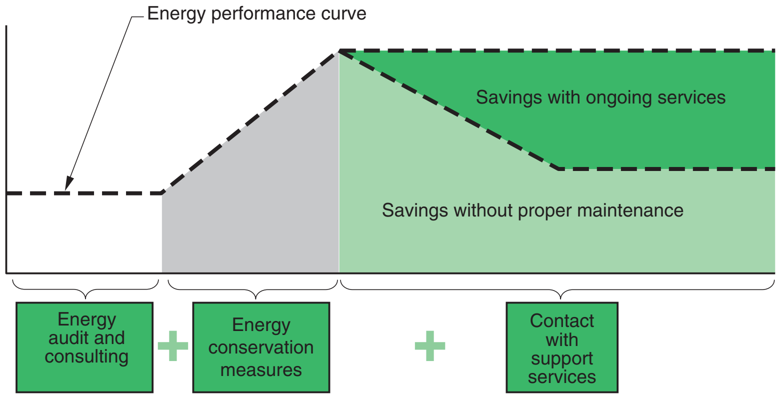


Fig. K30 : Ensuring performance is sustainable over time

A continuous improvement cycle will only work if there is an energy monitoring system in place, and this system is used effectively and maintained. The system supports a continuous and proactive analysis of energy use at the site, and informs recommendations for improving the electrical distribution system.

Support services, either on site or at a remote location (accessible via telephone, e-mail, VPN (Virtual Private Network) or any other type of long-distance connection), are often required to ensure optimal performance for this type of system and the best use of the collected data. Thanks to their contribution in terms of experience and availability, these services also complement the operator's in-house services. The services available may include:

- Monitoring the performance of measuring devices
- Updating and adapting software
- Managing databases (e.g. archives)
- Continuously adapting the monitoring system in line with changing control requirements.