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no. 206

Energy savings in buildings

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Energy savings in buildings

Irrespective of the building to be built or managed, there is a need for solutions to control energy consumption. This holds true throughout the world for all types of buildings, in the industrial, residential or service sectors.

Before designing or upgrading a building, and in particular its electrical installations, it is essential: to study its energy needs and the available energy sources; to find the best balance between management systems, distribution networks and consumer equipment; to take account of operational requirements.

This "Cahier Technique" presents a methodology for effective preliminary study work. The author therefore explores all of the elements which contribute to energy savings and which, depending on the installation, may or may not be selected.

Contents

1 Introduction

It is first of all advisable to identify the aims of each player concerned with the building under consideration and their needs in relation to energy management.

1.1 Players

The main players are:

- The operator, who may be the actual occupier of the building or a designated management company,
- The customer, i.e. the owner of the building, either as occupier or investor,
- The project manager: the architect or design department responsible for the construction of the building,
- The suppliers, in particular energy suppliers (electricity, fuel oil and gas distributors, etc.),
- The competent regulatory authorities for the building under consideration.

1.2 Needs

Needs of operators

All operators, commercial and industrial, have a pressing need to offer their products and services at competitive prices.
The operator's overriding objective is therefore to reduce energy bills through a lower tariff, through reduction of energy consumption and through government aid for the reduction of energy consumption, while simultaneously maintaining all of the services required for the correct operation of the operator's activities and for the comfort of the people occupying, working in and visiting the building.

Needs of customers

- to ensure conformity with current energy regulations,
- to benefit from grants for the installation of energy-saving systems,
- to increase and maintain the real value of their property.

Needs of project managers

- to remain competitive in terms of services and price at the time of selection,
- to remain within budget during installation work.

Needs of energy suppliers

- to optimize the operation of their networks,
- to control peaks in energy demand without oversizing their installations.

And, in the special case of electrical energy:

- to control reactive power,
- to control power quality (reducing voltage fluctuations, power cuts, harmonics, etc.).

Needs of regulatory authorities

The various official organizations which have authority over the design of buildings are given by the States the responsibility for implementing a general energy policy with the following main objectives:

- ensuring the long-term management of national energy supplies with a view to greater energy independence;
- ensuring a coherent approach to overall consideration of environmental aspects: global climatic warming, CO_2 emissions into the atmosphere, heat and pollutant emissions;
- ensuring that economic development is compatible with sustaining the environmental conditions to make it possible ("sustainable development");
- promoting and applying the international agreements relating to energy and the environment.

In certain cases, it is apparent that the various players have directly opposing interests: for example, installing a highly efficient heating system which is expensive to buy is an additional charge for the investor, but a saving for the operator. In other cases, the same player may simultaneously have two roles (e.g. in the case of an owner-occupier).

Hence the need for an overall approach which takes account of the energy costs, installation costs and equipment maintenance costs.

In addition there is the fundamental requirement not to reduce production capacity, nor the comfort level in the building.

2 Itemizing energy consumption and available energy sources

2.1 Energy consumption

We can first of all itemize the consumption of all types of energy used daily to perform the required functions in the building.

The industrial or commercial process in the building

"Process" here refers to all of the installations directly necessary for the professional activities of the building occupants. It includes:

- For a factory or a commercial building: industrial production machinery, information systems, installations for the handling and storage of materials and products (refrigeration of foodstuffs, for example), specialized fluid networks (compressed air, steam) required for production, etc.
- For a building in the service sector: information systems and special equipment (for laboratories, research, etc.).

These processes have very high consumption levels, representing in general the largest energy cost (except, for example, in office buildings). The quantity of energy consumption and the consumption profile of the process vary considerably depending on the activity under consideration (vehicle assembly plant, textile workshop, administrative buildings, hypermarkets, etc.). This is why any study of energy saving must be carried out in consideration of the process in its entirety to maintain or even improve production characteristics (capacity, reliability, etc.).

Systems for enhancing user comfort and building utilities

Included in this category are all systems usually found in a building which are not linked to its professional use. These are all of the systems for heating, air conditioning, ventilation, distribution of domestic hot water, lighting, communication, safety, distribution of various fluids (in particular compressed air), and the mechanical systems (elevators, hoists, escalators).

Energy consumption profiles vary widely according to the type, surface area, purpose, human occupation and standard of comfort in the building (see **fig. 1**).

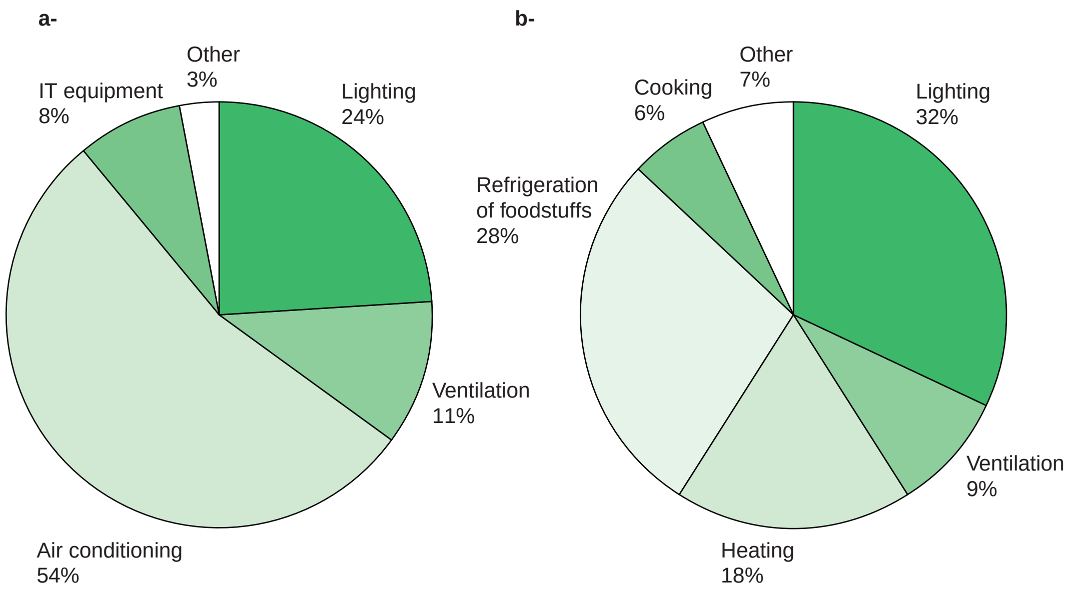


Fig. 1 : breakdown of annual energy consumption:
***a]** in an office building in South-East Asia, **b]** in a Western European hypermarket.*

2.2 Energy sources

It is possible to make use of all of the energy sources detailed below to supply the energy requirements described previously (see **fig. 2**).

Distributed energy sources:
- electricity,
- heat,
- natural gas,

etc.

Free energy sources:
- solar,
- wind,
- geothermal,

etc.

Stored energy sources:
- coal,
- fuel oil,
- liquefied gas,

etc.

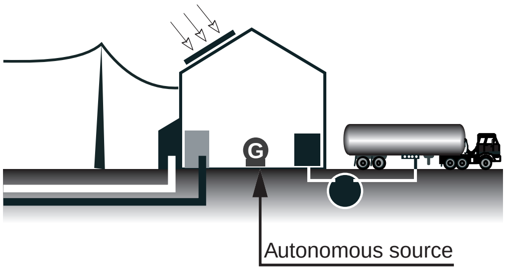


Fig. 2 : the various energy sources.

Supply via external networks

Energy is usually supplied to the building via public distribution networks for electricity, natural gas and district heating. Other types of public distribution networks can be found, but are much less common: steam, compressed air, various fuels, chilled water, etc.
These energy supplies are governed by subscriber contracts between the supplier (public or private, monopoly or otherwise) and the customers occupying the building.

Energy in the form of electricity is of particular importance, as it is virtually essential for all applications and buildings. Apart from certain marginal cases of isolated installations (mines, oilfields), there are very few completely autonomous installations. There is therefore always at least one connection to the electricity supply network.

The natural gas network is in general used for heating, domestic hot water, cooking, and sometimes the process itself. Billing is based on metering by volume (with its energy equivalent).

Public hot water distribution networks can sometimes be found, generally intended for heating buildings. These are frequently seen in major urban centers (a municipal scheme with boiler rooms, for example, for incineration of household refuse), in certain countries with a tradition of state control, and more recently in semi-rural areas, to make use of wood chippings, for example. Billing is based on metering by volume and the temperature differential.

Supply of stored fuels

In addition to connected networks, energy can also be delivered in the form of fuel stored on site. This is generally liquefied petroleum gas (propane, butane), domestic or heavy fuel oil, coal, which is still important in many countries, and wood when available locally: wood has been the object of recent technological applications.

These fuels can be used in boilers for heating, production of domestic hot water, hot water or steam for industrial use, and for driving local electrical generators.

The use of fuels stored on site offers partial or total autonomy in the event of interruptions to the service from external networks.

Autonomous electricity sources

It is often essential, given local environmental conditions, to acquire a means of autonomous production of electrical energy. Indeed, electricity distribution is insufficiently reliable in many countries: all too frequent and lengthy power cuts prevent normal industrial or commercial activities from being pursued. This is why, for example, many supermarkets in Latin American countries can produce 100% of their power requirements autonomously.

However, even in areas where electricity supply is highly reliable, certain activities require secure protection against interruption, no matter how rare. Thus hospitals throughout the world are equipped with adequate autonomous production to ensure the uninterrupted operation of vital installations.

Possession of an autonomous source is also the basis of energy management, making it possible to select the preferred energy source according to the time of day, the instantaneous power demand, and the hourly tariff of the external source.

- Auxiliary or safety generating sets

Such generating sets generally use stored fuel. In general, power is produced at a low voltage and the alternator output is connected to the internal electricity supply network. According to the individual case, the generating set and the external network can operate in parallel or separately.

- UPS - Uninterruptible Power Supply - commonly known as an inverter

Many installations have a UPS. These electronic power units are used to produce an AC current from energy stored in electric battery banks in order to maintain an uninterrupted power supply to critical or vital apparatus (data processing systems, hospital operating theaters, etc.).

■ Cogeneration

Cogeneration is a technique for the combined production of heat and electricity from one process, with a consequent reduction in heat loss. Various cogeneration models can be used:

□ The production of heat (or steam) which is necessary for the process is then available to produce electrical energy.

□ The process creates by-products (wood chips or paper waste, etc.) which can be burnt to produce heat and electrical energy.

Cogeneration is described in more detail in the appendix.

"Free" energy sources

Energy sources for which no charge is payable are grouped under this name.

■ Solar radiation

□ Solar panels have been used for several decades, even in countries with cold climates (e.g. Scandinavia). They absorb solar radiation and convert it into thermal energy. The main use of this energy, via a heat exchanging fluid, is for heating and the production of domestic hot water.

□ Photovoltaic cells, a more recent technology, convert light energy into electricity. Producing less power than thermal panels, they are often used to supply isolated homes or equipment (hertzian relays, street lamps, etc.).

The energy collected by these devices depends primarily on the weather conditions: it is generally necessary to have another source to provide 100% substitution.

■ Geothermics and heat pumps

Thermal energy from underground or from subterranean water sources (geothermics), or from the surrounding air by means of heat pumps is also free.

Note: Heat pumps are thermodynamic equipment designed to transfer thermal energy from one fluid (air or water) to another (air or water).

■ Wind power

Mechanical energy produced by the wind drives an alternator by means of a propeller. Electricity producers now operate modern installations (wind farms) supplying several megawatts. Private installations also exist, producing a few kilowatts to supply isolated buildings (farms, hotels, etc.).

With the exception of free energy, the suppliers (of electricity, district heating, fuel) issue bills for the energy from these various sources.

An analysis of all of these bills is the first step in reducing energy costs for the operator (see **fig. 3**).

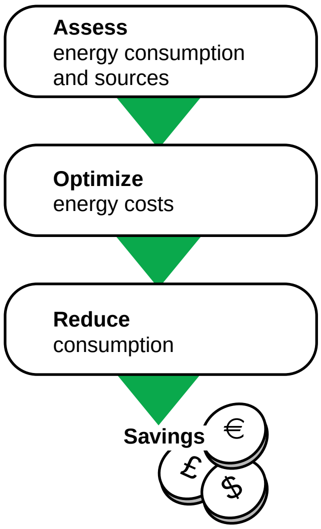


***Fig. 3** : general approach to energy control.*

3 Reducing energy costs

As stated above, the main motivation for decision makers to take an interest in energy control solutions is economic efficiency.
When deciding whether to invest in improvement work, the manager of a building, for example, must be convinced that the operation will produce immediate results as well as an acceptable time for return on the investment (from two to five years in most cases).
With cost savings thus the dominating factor, it is highly worthwhile to attempt to optimize the application of energy supply agreements before even considering technical changes to reduce actual physical consumption. It is thus a question of first trying to spend less rather than trying to use fewer kWh.

3.1 Analyzing energy bills

Although in this exclusively financial approach our primary interest is in the supply of electrical energy, we can compare this to the supply of other forms of energy. Supply is provided under a contract made with a supplier whose profile can vary considerably depending on the country: a state-owned company; public, mixed or private control of distribution; or a trading and services company in a competitive or monopoly situation.

Given these conditions, there is a large variety of contract types, and the choice widens as the power requirements for the site increase.
In many countries where the electricity sector is in the process of privatization, consumers have access to a competitive market when their needs exceed a so-called “eligibility” threshold.

An electricity bill generally displays the following items:

- standing charges: subscriber and other charges (maintenance, services, etc.),
- variable charges corresponding to:
  - the supply of metered energy, a cost which may be quite complex and comprise several tariffs,
  - the maximum power reached or subscribed to:
    - the active power in kW or apparent power in kVA which includes the reactive power,
    - as an instantaneous value or an average value over a time interval.

    There can be one or more accounts according to time or period; there may also be a penalty for exceeding an agreed threshold;
  - the reactive power consumed, in general metered above a tolerated threshold,
  - other variable charges and services.
- taxes.

Depending on the country, the electricity bill may therefore be complicated or even extremely complicated. It is thus essential to include how it is calculated, and to have a thorough knowledge of the electricity needs of the building in order to determine possible areas of improvement.
The first area for improvement is the best use of the existing contract, and the second is the renegotiation of this contract with the supplier.

3.2 Using the existing contract

There are several possible approaches to make the best use of the existing electricity supply contract.

- Limiting the power demand from the distribution network by using the existing available internal sources (generating sets). This avoids any oversizing of the subscriber contract or exceeding of the contract limit and leads to a reduction in total energy costs. To assess the economic impact it is therefore also advisable to know the cost of the alternative energy source, for example the efficiency of the generating sets and the price of the fuel consumed.
It is obvious that replacing the electrical energy provided by a distributor with energy produced on site is more cost-effective during the most expensive times (peak hours) under the contract.
This economic advantage of using an internal source is inextricably linked to another very significant advantage: the possibility of overcoming any interruption in the external supply and of maintaining essential services.

- Optimizing reactive power by installing a compensator to avoid any invoice penalties (which also reduces active power losses).

- Switching consumption where possible to the least expensive tariff periods. Some energy consumption can be deferred without reducing either productivity or the comfort of occupants by managing the devices which consume energy via an automatic control system.

This solution is usually applied to the production of domestic hot water with storage water heaters (hot water tanks) and for electrical storage heating systems.

Another application in certain countries is to use large volumes of ice formed during low tariff periods in cooling systems for air conditioning.

In all cases, unless it is a question of simple load shedding which is temporarily preventing an operation or service, the installation must be designed to enable this type of operation.

3.3 Renegotiating the contract

If optimum use is already being made of the existing electricity supply contract, it is still possible to negotiate a modification, for example by adapting the subscribed power demand in the contract to building activity (the right quantity of energy required distributed over time).

It goes without saying that the bigger the consumer, the more flexible the supplier will be, even in a monopoly situation: distributors may also have difficulties in managing their energy resources.

Negotiation is of course easier if there is competition in the supply of energy. The requirements of the various suppliers are not the same, and their proposals may therefore differ, with adaptation to the needs of particular customers.

In certain countries, it is possible to sign a single contract with one energy supplier to supply several establishments managed by the same company or by an interest group consisting of several independent companies. The sites concerned are not necessarily in the same geographical area: they may even be in different regions of the same country, or in different countries if those concerned have international interests. These “multi-site” contracts can be used to optimize electrical energy management with more flexibility, provided there is full control of their complexity.

It is sometimes possible to draw on several energy suppliers according to need. In certain countries, suppliers and major purchasers can be brought together by means of “Energy Markets”: they then directly negotiate the quantities of energy required from day to day. Access to this market, which permanently offers the best price opportunities, is of course reserved to the largest customers.

4 Reducing energy consumption

As savings in terms of costs are the main concern for the operators, the first approach, as outlined in the previous section, is to try to pay less for the same amount of energy.
This approach is the easiest as it does not require any radical change to behavior or installations.

The next step of the approach requires that a smaller quantity of energy be used to achieve the same result.

Reducing consumption is also strongly encouraged by the requirements of the regulatory authorities (see Section 1).

This involves technical modifications to the design of future or existing buildings, the design and implementation of improvements, the adaptation of new systems, and even changes to the procedures and behavior of users. Separate from the process, the power consumed by the functional systems in the building must be reduced (while maintaining output and comfort) as described in the following subsections.

It should however be stressed that this approach contributes to the improvement and modernization of production equipment (providing new solutions in terms of both performance and quality): it thus also satisfies a professional requirement.

Generally, for a building containing an industrial process, the main area for savings lies in the production equipment, which must therefore be studied with specialists in the relevant application area.

4.1 Savings in the HVAC system

HVAC is the professional term for the Heating, Ventilation, and Air Conditioning functions.

HVAC systems are designed to maintain the inside temperature and ambient air at comfortable levels. It should however be noted that the variety of climates around the world has led to different situations:

- in countries with equatorial or tropical climates, “comfortable” means cooling the buildings;
- in countries with temperate coastal or continental climates, heating is essential in winter, while air conditioning is useful (and sometimes essential) in summer.

In many buildings, HVAC is the first or second item in terms of energy costs.

Heating

Heating systems have always been used when the outside temperature drops below a certain comfort threshold (a highly relative concept in terms of time and space). The majority of countries in Africa, South Asia and Latin America do not use heating.

The choice of the type of heating and its energy source must be made at the outset when designing a building: it falls within the competence of the specialists, architects and heating engineers.

In all cases, the search for savings involves the following actions.

- Limiting heat losses from the building

Depending on the level of and variation in the outside temperature, heating or cooling (air conditioning) systems maintain the inside temperature at a comfortable level (typically from 18 to 22°C). In constant operation, these systems add or remove the exact amount of heat necessary to compensate for heat losses from the building (see **fig. 4** next page).

The first step is to minimize these losses. To do this, it is possible to:

- design the external walls to limit heat conduction and dissipation by radiation,
- insulate the roof,
- use doors and windows with heat insulation (double glazing, insulated doors),
- treat cold bridges (door and window frames, load-bearing structures such as pillars or beams, etc.),
- provide screens (shutters) to reduce losses through openings,
- adapt sun-screening devices to avoid solar radiation when cooling is required.

All of these actions are made easier when they are embarked upon as part of the design of a new building, and are thus less expensive than in existing buildings where there are constraints on insulation and restoration work. Cheaper solutions can however be applied to existing buildings, in particular by reducing the amount of outside air which enters the building through the opening of doors and windows, or by providing an entry chamber.

In all buildings, effective heating management can also produce savings:

- Prevent simultaneous use of heating and air conditioning

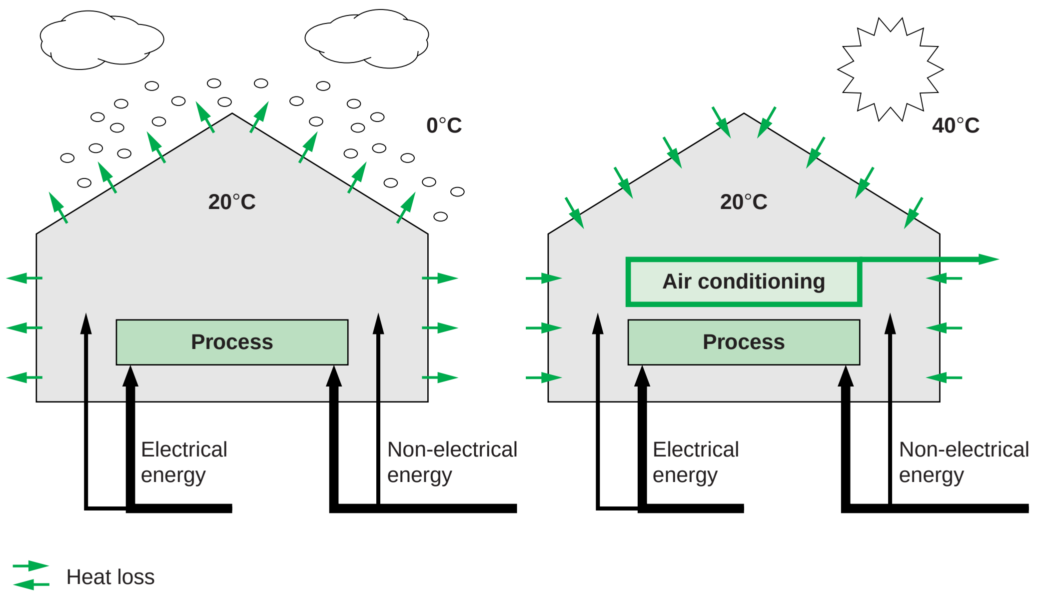


Fig. 4 : energy flows in buildings.

■ Avoid any improper use of heating:

□ In all buildings housing commercial, industrial or administrative activities, a temperature of 20°C to 22°C should not be exceeded during heating periods. Temperature settings are necessarily higher in hospitals and health centers, while colder ambient temperatures are possible in gymnasiums and sports halls.

□ Prevent or limit the opening of windows (both during cold spells and heat waves) or make individual heating (and cooling) systems dependent on the windows remaining closed.

□ Do not heat, or if necessary maintain just above freezing, unoccupied or partially occupied buildings (storage and service areas). For individual offices, rooms, etc., it is possible to control the operation of local heating, or the opening of air vents, by a presence detector.

■ Optimize the output of heat generators

Heating systems can be either individual or centralized.

□ Individual systems generally draw on electric radiators (convector, radiant or blower type) which heat each area of the building separately (offices, rooms, common areas). However, although the efficiency of an electric radiator is 100% (all of the energy used is converted into heat in the building), this type of heating is seldom the most economical. To be effective, it must be controlled so as to switch off the heating once a room is no longer in use.

□ Centralized systems include a heat generator (boiler) and a distribution system. When heat is purchased from a supplier, the energy is delivered via hot water pipes and thermal metering is used for billing purposes. In other cases, thermal energy is generated in a boiler located in the building. To be fully efficient, a boiler must be of recent design and adjusted and maintained by qualified personnel. Its efficiency can be measured, regardless of the type of fuel, by monitoring the level of CO_2 and the temperature of the exhaust gases.

■ Use heat pumps

Heat pumps can be used alone or in combination with a boiler, with the type used depending on the heat source.

□ The heat source may be the surrounding air, but in this case the pump cannot be used effectively below a certain temperature, because of icing. “Air-water” or “air-air” heat pumps are thus most frequently used in mid-season, with the boiler taking over during the coldest periods.

□ The heat source may also be subterranean water, where available (see **fig. 5** next page), or the subsoil. The heat pumps are in this case of the “water-water” type and have a much greater range of use, as they are not limited by the outside temperature.

Note: The efficiency of a heat pump is measured by its coefficient of performance (COP), which is the ratio of the thermal energy delivered under specified temperature conditions to the electrical energy consumed by the compressor (and possibly the fan).

The COP of an “air-water” heat pump is 2 to 3.5 depending on the air temperature. A “water-water” heat pump can achieve a COP of 3 to 5.

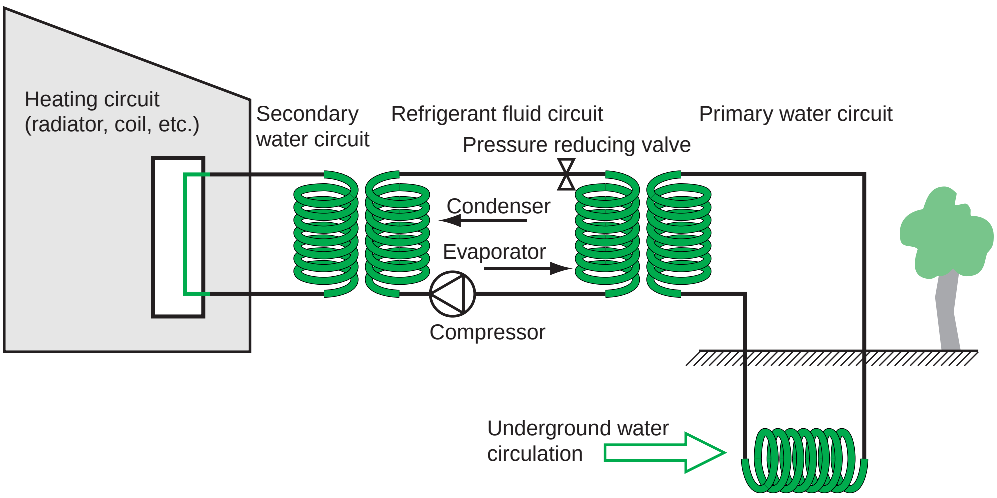


Fig. 5 : *"water-water" heat pump.*

■ Use solar heating

This solution presents two difficulties: it requires good exposure (orientation) for the installation of the solar panels, and the availability of heat is by its very nature subject to variations in the weather. It can only be used as a supplement to heating.

■ Optimize heating circuits

In the case of a centralized heating system where thermal energy is distributed to various buildings via a water or air circuit, it is also advisable to save energy by reducing heat loss along the pipes. It is essential to insulate water pipes or air flues, especially in unheated areas (ducting, boiler rooms, service areas).
The electricity consumption of pumps or fans must also be reduced by fitting variable speed drives to provide a level of propulsion which exactly meets the requirement.

■ Optimize heating control

The heating control system must ensure the user comfort at minimal energy consumption (see **fig. 6**).

In normal operation, all of the premises which are actually used must be at a comfortable temperature. For periods when the buildings are not being used (nights, weekends, holidays) the temperature can be lowered by several degrees.
A minimum temperature just above freezing must be permanently maintained to avoid damage to buildings and their contents.

Such optimization requires programming which must take account of:

□ The thermal inertia of the building. The heating must therefore come on a few hours before the occupants arrive, and it may similarly be switched off before they leave. It is highly worthwhile to fine-tune these periods, even with a temporary slight drop in the level of comfort.

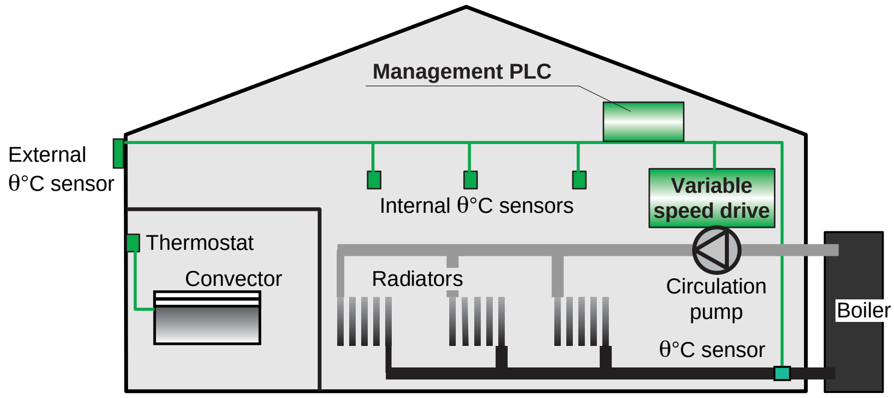


Fig. 6 : *water heating circuit.*

□ The occupation of premises where it is possible to regulate the temperature of various parts of the building independently, thus avoiding heating unused rooms or rooms which are only used intermittently.

□ The external climate (outside temperature, wind, sunlight) in order to estimate the heat loss from the building.

□ The “free contributions” provided by solar radiation, the metabolism of those present (approximately 75 W/person), as well as heat generated by processes (for example cooking) and interior lighting. These free contributions are taken into account by the internal thermostats.

Finally, to improve user comfort, it is desirable to be able to adjust the temperature setting for each office individually. Adjustment is by means of either a thermostatic valve controlling a water-filled radiator or a shutter controlling the air flow.

Cooling the ambient air (air conditioning)

This is necessary in countries with hot climates, and is now used more and more in temperate regions during the summer months. It makes a significant, often indispensable, contribution to comfort and is also a significant item of expenditure in terms of electrical energy for the building.

Two types of installation are possible: individual units for each part of the building (offices, rooms, etc.) or a centralized system consisting of a bank of cold generating sets and a cold distribution system using air or water.

Basic operation is the same in both cases: a refrigerating circuit with a compressor absorbs heat from the air inside and expels it to the outside of the building (see **fig. 7**).

Most of the solutions previously described for heating can be used to reduce the energy consumed by air conditioning. It should however be stressed that:

■ It is preferable to have a temperature setting of about 25°C: this is fully compatible with comfort and efficiency.

■ Cooling systems require regular maintenance. Any leak of refrigerating fluid will cause a sharp fall in the efficiency of the unit. In the same way, the cleanliness of the exchangers considerably influences their effectiveness.

■ New systems generally offer optimum efficiency as their internal parameters (pressure, speed, etc.) automatically adapt to current temperature requirements.

It should be noted that, contrary to heating, there is no free contribution to cooling and that any release of thermal energy (for example by incandescent lamps) in a cooled building increases the cost of energy absorbed by the compressor (see **fig. 8**).

Renewing the ambient air

This consists of extracting air from inside the building which has become stale through the activity in and use of the building, and replacing it with the same quantity of “fresh” air from outside. This function is related to heating and air conditioning, as:

■ The air distribution system is often used to adjust the temperature.

■ The temperature of the injected outside air must be adjusted to the set point temperature. This thermal requirement represents another energy loss from the building.

■ In mid-season, when neither heating nor air conditioning are required, energy expenditure is 100 W.

■ In a period requiring heating
The heat release is taken into account by the thermostat which reduces heating consumption and the resultant lighting cost is zero.

■ In a period requiring air conditioning
The compressor consumption (typically 30%) required to evacuate the heat must be added to the lighting consumption (100 W). Total expenditure thus amounts to 100 + 30 = 130 W.

***Fig. 8** : influence of free contributions: simple example of a 100 W incandescent lamp.*

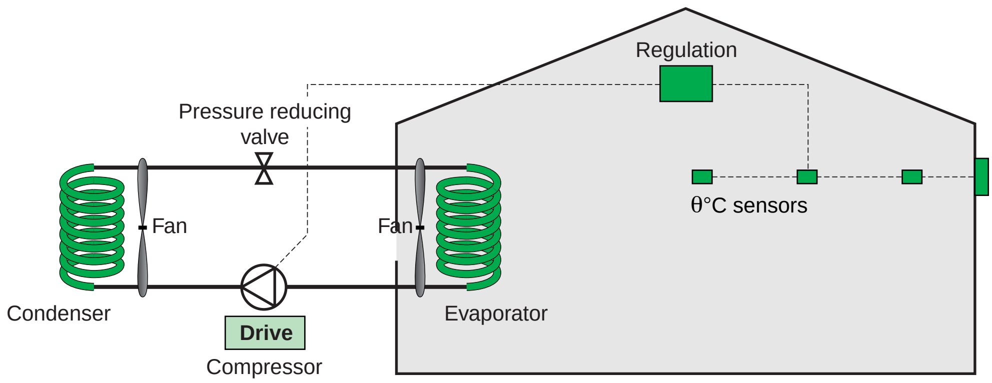


***Fig. 7** : air conditioning refrigerating circuit.*

Renewing the ambient air is a significant item in energy consumption (see **fig. 9**). There are various possible ways of reducing it.

The existing system consisted of an air treatment unit and two 16 kW motors (extractor and blower) running at 1,400 rpm.

To reduce the flow of air extracted and injected when the rooms have a low occupation rate, the solution was to equip the two motors with variable speed drives and control them via a programmable timer.

Installation cost: € 5000

Annual savings: 22% of ventilation costs, i.e. € 1900

Time required for return on investment: 2.6 years

Fig. 9 : example of savings made by modifying the ventilation installed in the bedrooms of a large hotel (source: Schneider Electric).

■ Controlling the air extraction

A comfortable environment for the building occupants requires an air renewal system, as:

□ the temperature and the humidity must stay within specified limits,

□ the concentration of pollutants of whatever nature (resulting from the industrial activities of the building occupants) must remain within acceptable limits,

□ carbon dioxide (particularly that produced by the breathing of the occupants) must be extracted from the building.

This is why air renewal systems are obligatory, and their importance in ensuring the safety and comfort of the occupants increases in proportion to the number of occupants.

All buildings thus have an air renewal system for all rooms in the building. They are generally centralized systems with an air treatment unit and a network of ducts. In general, these systems are designed to operate during periods of maximum occupation of the buildings (with the usual occupants and occasional visitors). However, during normal occupation, this oversizing of the air flow represents a significant waste of energy. Controlling the air flow extracted according to the CO_2 concentration inside the building allows system operation to be adjusted to meet demand. With several CO_2 level detectors, it is possible to adjust flows by zone (see **fig. 10**).

Note: In parking garages, the carbon monoxide (CO) level emitted by vehicles must be controlled and substantial savings are also possible by adjusting the ventilation flow to actual needs.

■ Mechanical ventilation with heat recovery

During heating or cooling, renewing the air inside means expelling air at 20°C and replacing it with air at 0°C which must be heated (or with air at 40°C which must be cooled). To reduce this energy loss, a counter-flow exchanger can be installed between the air intake and outlet to transfer energy from the hottest to the coldest flow.

Possible savings are significant, but this system must form part of the design of the building, for example in the provision of ducting.

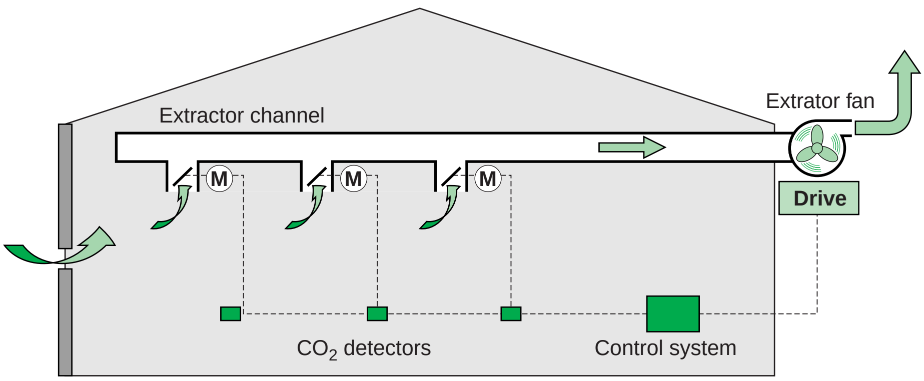


Fig. 10 : ventilation controlled by CO_2 level.

4.2 Savings on domestic hot water

A difference must be made between hot water required for processes and domestic hot water. Hot water used in substantial quantities for a production process is generally the subject of specific treatment (see the section on Cogeneration in the appendix).
Domestic hot water, generally used for hygiene purposes, but also for specific functions, such as in kitchens or bars or for cleaning buildings, is an integral service of the building.

There are several possible solutions for saving energy used in the production of hot water, which may even be used together.

Measure hot water consumption (volumes consumed) by building area, department, etc. in order to locate abnormal consumption, make users act more responsibly, and if possible charge the costs to them.

Detect and stop hot water leaks

A hot water leak, however small, represents a significant volume of the quantities used as it is permanent. The waste can thus be considerable compared to the effective energy consumption. It is thus advisable to ensure correct maintenance of valves and fittings.

Avoid unnecessary consumption

Choose valves and fittings with a presence detector or an automatic cut-off, or sanitary equipment which uses water economically.

Optimize temperature settings

Optimize the production system settings: for sanitary purposes, the temperature should not exceed 55°C, but for personal comfort 45°C is sufficient.

Install and optimize a circulation loop

There should be a distance of no more than ten or so meters between the points of production and use, to avoid the water coming cold too long. Apart from the perceived loss of comfort to the consumer, the volume of hot water actually consumed is the total quantity drawn, and the majority of energy is lost as it is used to heat the pipe with each use.

In practice:

- in non-residential installations, distributed production is necessary (a water heater within 10 meters of each point of use);
- in buildings where there are many user points (hotels, for example), there is a loop for hot water to circulate in the immediate vicinity of user points. The pipes must be effectively insulated and the circulating pump flow must be adjusted to obtain a return temperature which is just adequate (40°C) if no water is drawn. To do this, it is worthwhile using a variable speed drive to regulate the pump. Finally, it is also possible, depending on the usage curve, to halt circulation when it is statistically unlikely that there will be a need for hot water.

Use a heat pump dedicated to domestic hot water

There are domestic hot water production units which use heat pumps, with either the outside air or the ambient air in the service area used for heating acting as a heat source. This solution is of interest as it can function all year round. It is particularly worthwhile in countries with hot climates, where it offers savings of 60% compared to direct electric water heaters. In countries with cold seasons, a backup by resistive heating is necessary.

4.3 Savings on lighting

Lighting is an essential service in all buildings: it contributes to the safety and comfort of occupants and to the productivity of activities. It is often a very significant item of energy expenditure, indeed sometimes the main item. The main approaches to saving energy with regard to lighting are as follows:

Reduce the installed power levels

Use lamps of recent design which have a considerably lower nominal power for the same luminous flux, in particular fluocompact lamps (-70% compared to incandescent lamps) or modern small diameter fluorescent tubes (-30% compared to traditional tubes); use lamps with electronic ballast (-20% compared to ferromagnetic ballast).
Use luminaires of recent design in which the optics make the best possible use of the luminous flux emitted by the lamps.
Savings on the electricity consumption bill are thus doubled, owing to the longer service life and the simplified maintenance required by improved equipment. Lighting quality is also improved.

Remove unnecessary lighting

■ According to the natural lighting level

□ In a building, areas close to outside windows require less in terms of lighting than darker areas inside the building. By taking account of this common sense observation, it is possible to save a proportion of the energy consumed which varies according to the natural internal lighting during daylight hours and which must obviously be supplemented during working hours once night falls. This function can be provided by a lighting control device integrating a light meter or by power controllers inserted in the luminaires which automatically vary the flux emitted according to the outside light levels (see **fig. 11**).

Replacement of permanent lighting by automatic lighting on detection of presence using a programmable time switch:

■ The detectors used have a detection radius of 12 m and can control up to 500 VA of fluorescent tubes or fluocompact lamps. They are installed in the ceiling every 20 m to ensure that all detection zones are covered.

■ The time switch performs the following operation: in times of heavy use, 50% of the lamps are permanently lit and 50% come on when a person goes past. During off-peak hours, 50% are off and 50 % come on when a person goes past.

Installation cost: € 2000
Annual savings: 50% of corridor lighting, i.e. € 1200
Time required for return on investment: 1.7 years
Note: Emergency lighting is already in place.

Fig. 11 : modified lighting installations in the corridors of a large hotel (source: Schneider Electric).

□ It is also possible to reduce outside lighting (parking lots, alleyways, accesses) in the darkest hours. However, as the eye requires more artificial lighting in half-light (at dusk) than when it is dark, it is advisable to fit a lighting level detector and a clock to ensure progressive reduction in the supply voltage to the light sources.

■ According to the presence of the occupants

With the exception of a minimum level of safety lighting, permanently lighting unoccupied or intermittently occupied areas is unnecessary. Corridors, staircases and landings are only crossing points and there is no permanent human presence in storage and service areas.

The traditional timer already produces significant savings.

For improved performance and comfort, presence detectors are available which can also be integrated into luminaires: when a movement is identified, they control the activation of lamps in the vicinity: these remain lit as long as any movement is detected. In the absence of movement, the lamps go out after a set time period (which can be adjusted from a few seconds to a few minutes).

Design an automated lighting management system

Automated systems which communicate with the various equipment (luminaires, switches, detectors, measuring apparatus) are used to control lighting separately by geographical area, by type of individual luminaire, by function and individually. These systems are user-definable, reconfigurable and flexible. The greatest possible energy saving is offered together with maximum comfort for users.

4.4 Reducing electrical energy losses

The electricity supply network itself consumes energy. Moreover, if it is not suitably designed or adapted to user needs, the network is a cause of energy waste and at the same time will not provide satisfaction in terms of power quality and availability.

Improve the power factor

Reactive power is consumed in the magnetic circuits of loads such as motors and by non-compensated fluorescent lighting. If not corrected, the current circulating in the conductors increases although the same level of active power is being used. A significant number of these self-inductive loads involve a phase shifting of the current and the voltage in the electric installation on the site. The cosine of the angle of this phase shifting is called the power factor: $\cos \varphi = PF$.
For $\cos \varphi = 1$, the current and the voltage are in phase and the current is minimal; the greater the deviation from this ideal value, the greater the degradation of operation with the following consequences:

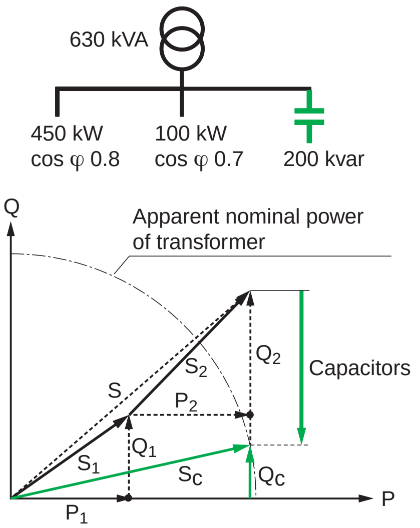
■ overcurrent on the electricity supply network on the site and on the public power supply network,

■ additional energy losses (Joule effect) across the network,

■ overloading and overheating of the transformers and a reduction in the available active power (see **fig. 12** next page),

■ an end-of-line voltage drop which can induce abnormal operation of certain sensitive devices,

■ in many cases, a financial penalty charged by the energy distributor (whose installations are also overloaded by the reactive power consumed by their customers), the calculation of which varies according to the country and the distributor.



The requirement

To add a power load P_2 = 100 kW with cos φ = 0.7 to an existing industrial facility with a power transformer Sn = 630 kVA, to supply an overall active power load P = 450 W with cos φ = 0.8.

Preliminary checking

The apparent power consumed is
$S_1 = P_1 / \cos\varphi = 450 / 0.8 = 563$ kVA

and the reactive power is

$Q_1 = \sqrt{S_1^2 - P_1^2} = 338$ kVAR.

The apparent power of the additional load is
$S_2 = P_2 / \cos\varphi = 100 / 0.7 = 143$ kVA

its reactive power is

$Q_2 = \sqrt{S_2^2 - P_2^2} = 102$ kVAR.

The total apparent power to be provided by the transformer is $S = \sqrt{P^2 + Q^2}$

where $P = P_1 + P_2 = 550$ kW
and $Q = Q_1 + Q_2 = 440$ kVAR i.e. S = 704 kVA.
The new power factor is
cos φ = P / S = 0.78.

The result

The power of the existing transformer is insufficient to supply the overall load.

The solution: Reactive power compensation

Define the capacitor bank: to do this the corrected reactive power must allow the inequality:

$S = \sqrt{P^2 + Q^2} < 630$ kVA therefore:

$Qmax = \sqrt{S^2 - P^2} = \sqrt{630^2 - 550^2} = 307$ kVAR

It is thus necessary to provide at least:
Q - Qmax = 440 - 307 = 133 kVAR to give a minimum cos φ = P / S = 550/630 = 0.873

UA 200 kVAR capacitor bank is installed to give:
Q = 440 - 200 = 240 kVAR and

$S = \sqrt{P^2 + Q^2} = \sqrt{550^2 + 240^2} = 600$ kVA

where cos φ = P / S = 550 / 600 = 0.917.
The cost is € 12,000 (automated capacitor bank).

Advantages

- Savings
  - in active power corresponding to the heating of the circuits: 3,000 kWh / year, i.e. € 200 / year
  - in the maximum power demand (in kVA): € 2,500 / year,
  - In removing € 7,000 p.a. in penalties (halt to consumption of 250,000 kVARh p.a.).
- It is not necessary to replace the transformer with a more powerful model: a power reserve is still available.
- Operation of the transformer under better conditions leading to a longer service life.
- A short time required for return on investment: 1.3 years.

***Fig. 12** : extension of an industrial network with reactive power compensation (source: Schneider Electric).*

The solution to this problem is to install reactive power generators (capacitors), either closest to the loads which consume it (local compensation) or at selected points on the electricity supply network (central compensation).
Compensation is on the low voltage part of the electricity supply network and sometimes, in the case of more powerful installations, on the medium voltage part.
Correct compensation enables the operation of an installation to be maintained at a power factor of higher than 0.93, which is regarded as satisfactory.

However, installations do not permanently function in the same configuration: circuits are switched, loads are activated or removed, motors start and stop. It is also undesirable to leave the compensation calculated for maximum loading permanently connected, as there is a risk of “over compensation” leading to overvoltages which can damage the installation and the equipment. In practice, optimum compensation is possible using capacitors grouped in “steps”, with each step connected to the electrical circuit via a contactor controlled by a regulator subject to the measured power factor.

Reduce the harmonic ratio

“Harmonics” (currents or voltages with a frequency which is a multiple of the 50 or 60 Hz operating frequency) are generated by certain “non-linear” equipment, in particular those containing electronic components: domestic equipment, computers, inverters, variable speed drives, etc. They are superimposed on the current or voltage in the electricity supply network.

These harmonics travel upstream on the network and create a form of pollution for all other equipment, some of which is very sensitive. They are also the cause of energy losses due to the Joule effect which may reach 10%, in conductors, transformers and all other equipment.

Preserving the quality of electrical power (wave form, frequency, etc.) requires that these harmonics be reduced or eliminated: to do this, anti-harmonics filters are installed which are adapted to the network and the equipment in the building: their design requires highly specialized study.

In extremely specific industrial cases (furnaces used in metallurgy, welding machines) these filters are inadequate and the electricity supply network must be designed to take account of this function.

Reduce heat losses on the electricity supply network

These losses are produced by current flowing through all parts of the electricity supply network in the building (the Joule effect).
The replacement of old apparatus or equipment by more modern hardware can significantly reduce these losses:

- distribution transformers (up to 3 MVA)

Technological developments in materials and in particular laminations can reduce no-load losses from 15% to 20% irrespective of whether the transformer is of the oil-filled or dry type.

- electrical switchboards and enclosures

Research into distribution architectures has made it possible to reduce conductor lengths by approximately 40%, thus reducing energy losses due to the Joule effect by approximately 30% (see **fig. 13**). Moreover, there is a possibility of savings through the choice of the electrical switchgear integrated into the switchboard.
This is the particular case of contactors, which often appear in some numbers in automated systems: for example, whereas the old “model D” contactor-circuit breaker unit on a 20 A motor-starter consumed a steady 20 W, a “model U” (Telemecanique brand) only requires 7 W.
Such reductions can also avoid the need for air conditioning in the electrical room.

- UPS (Uninterrupted Power Supply)

Inverter efficiency varies according to the characteristics of the load supplied (in particular the power factor): modern technologies have allowed a significant improvement in inverter efficiency (which rises in importance as the power factor increases) of about 10% to 15% compared to older systems. Depending on the power of the secure network, it is therefore possible to make appreciable savings by replacing old inverters.

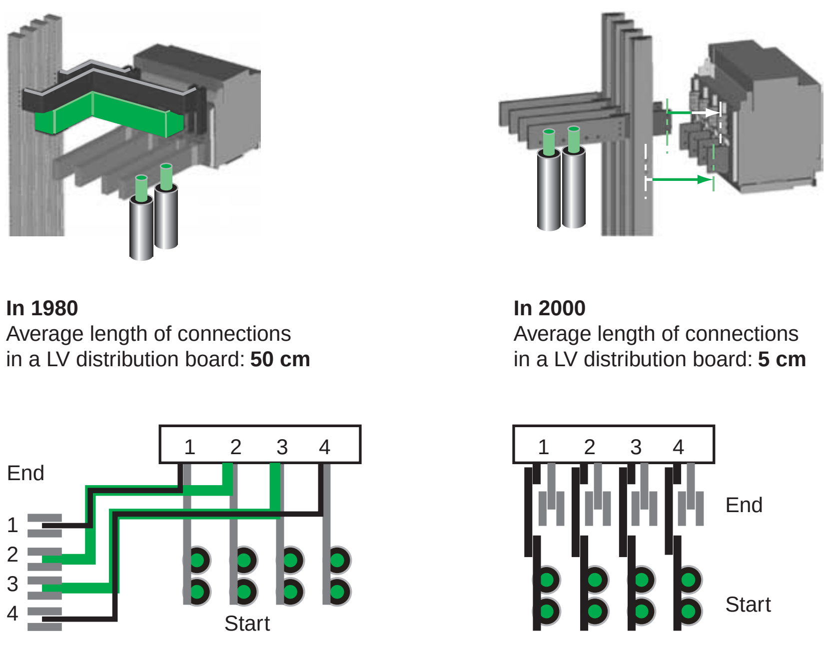


Fig. 13 : evolution of the architecture of an electrical switchboard between 1980 and 2000 (source: Merlin Gerin Alpes).

4.5 Other savings

Savings on fluids

The production and distribution systems for both compressed air and steam which have been primarily developed for process needs are very important areas for energy savings.

Water distribution can also be the subject of economy measures, especially in high buildings where pumps are necessary to ensure sufficient operating pressure.

The economical distribution of these fluids obeys the same rules:

- adapt the pressure settings to the level strictly necessary for correct operation,
- automatically adjust pump operation to demand and reduce the number of start-ups via the use of variable speed drives on the pump motors,
- detect and eliminate any leak which would make the pumps function unnecessarily,
- stop the pumps during periods of non-occupation.

Savings in the operation of mechanical systems

The elevators, hoists, escalators and handling systems are driven by electric motors with a large number of start-ups and significant load variations.
Energy savings are also possible here via thorough maintenance carried out by professionals and supplemented by regular inspections (consumption irregularities often herald a breakdown).
Controlling the motors with variable speed drives offers greater flexibility of operation in addition to reducing consumption.

4.6 Advantages of correct maintenance

The majority of the systems providing comfort and building utility systems must nowadays undergo periodic preventive maintenance for the same reasons – increased competition and tighter schedules – as processes. This maintenance can also be supplemented by a continuous inspection of system status. For example, when a simple electric motor begins to operate abnormally as a result of a manufacturing fault, of exceeding its normal operating conditions, or of wear, this almost always results in abnormal heating, slowing, a fall in its power factor and excessive consumption. This fault will sooner or later lead to a breakdown, and, as long as the fault is not detected or corrected, consumption will remain excessive.
Maintenance therefore limits the quantity and length of service interruptions and maintains the efficiency of equipment within its respective nominal ranges.

4.7 Importance of metering

The same holds true for all buildings in collective use: individual behavior and consumption change according to whether the charges for a common service are shared or are billed according to individual consumption.
This may appear obvious, but one of the most important sources of savings is the behavior of individuals. Any organization aiming to reduce costs must therefore make all of its departments responsible for achieving savings.
Installing and reading appropriately placed service energy meters, with the possible attribution of actual costs (by department, by workshop, by floor, or by functional system) to make the people concerned aware of this, is the first stage. These meters can simultaneously measure reactive power, voltage drops and harmonic currents. A device (PLC or computer) can be dedicated to centralizing measurements and establishing management tools.

The second stage is the analysis and comparison of consumption to highlight necessary local corrective actions. For heating and air conditioning, such metering can be supplemented by the metering of thermal energy and/or temperature readings to check or modify the settings.

4.8 The energy audit approach

This is the approach (see **Fig. 14**) a company should follow when it is concerned about controlling energy consumption in a building:

- Collate all necessary information
  - Know the distribution of energy consumption of the building by function and by sector (floor, department), notably with partial meterings if available. All types of energy must be considered additively.
  - Look for reference models representative of the activity and of the type of building.
- According to the available information, perform complementary metering if necessary. For example by installing sub-metering devices, in suitable number, in the main repartition points of the networks, for electricity and for other energies as well (gas, fuels), and for hot water, compressed air, …
- Comparing the measured consumptions by function with reference values allows identification of the less effective functions (rudimentary or obsolete equipment, perfectible management or organization).
- Draw up and cost preliminary projects of improvement works that can meet the most important savings, then select one ore more of the projects according to their efficiency and to the return on investment.
- Carry out the material and organization modifications; inform and teach users, promote new behaviour.
- Draw up the balance of the operation: the total energy consumed gives a first result of the approach.

Measuring the new partial consumptions allows the assessment of the implemented solutions. However the impact of the work carried out must be estimated with realism by taking account of the climatic variations, the level of activity and the degree of building occupation, the number of working days, etc.

On the basis of these results, validate other energy saving projects.

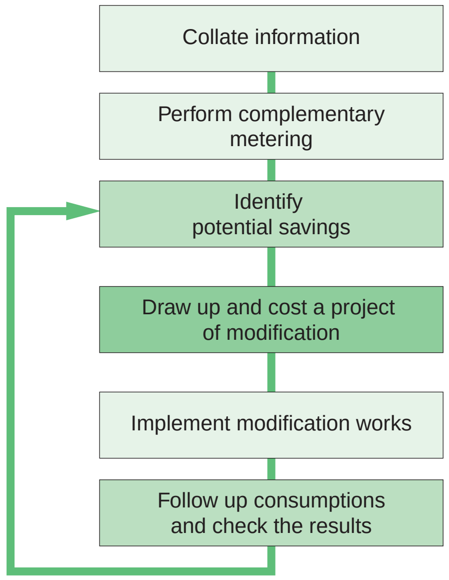


***Fig. 14** : procedure for reducing energy consumption.*

5 Case studies

5.1 Optimizing energy bills in a hospital

The hospital, located in a Latin American country, sought to reduce its electricity costs.

Continuity of supply is obviously a major requirement in the case of health facilities; the installation therefore comprised three power generating sets to overcome any interruption in supply.
Examination of the electricity bills highlighted:

- highly significant additional costs corresponding to the power demand during "peak hours" defined by the utility,
- penalties for excessive consumption of reactive power.

The solution proposed and implemented includes:

- installation of an automatic control system for the operation of the three existing generators,
- installation of capacitor banks for reactive power compensation,
- a device to monitor the demand for electrical energy.

Comparison of the billing totals before and after modification highlighted a total saving of 17% (see **fig. 15**).
Taking into account the price of the work carried out, the time required for return on investment was estimated at 2.6 years.

	Before US$	**After** US$	**Saving** US$	%
Fixed charges	13	13	0	0
Other charges	1,092	1,092	0	0
Energy	121,768	111,296	10,472	9
Maximum demand	17,600	15,840	1,760	10
Peak demand	49,308	0	49,308	100
Peak penalty	1,525	0	1,525	100
Generator operation		30,583	-30,583	
	191,306	**158,824**	**32,482**	**17**

Fig. 15 : comparison of the electricity supply bills in a hospital before and after modification.

5.2 Installation of ventilation with a variable speed drive

In the vast majority of ventilation installations the fan is driven by a motor connected directly to the network. The motor can thus only run at its nominal speed.

The air flow circulating in the ducts is altered using vanes or shutters fitted upstream or downstream of the fan, the angle of which determines the cross-section of the duct and the flow.

Fitting a variable speed drive removes the need for vanes as the air flow is regulated solely by the motor rotation speed. There are several advantages (see **fig. 16**):

- starting is gradual, with no current peak, reduced noise and no motor overheating;
- the power factor is significantly improved, both on starting and during operation in steady state;
- motor service life is increased;

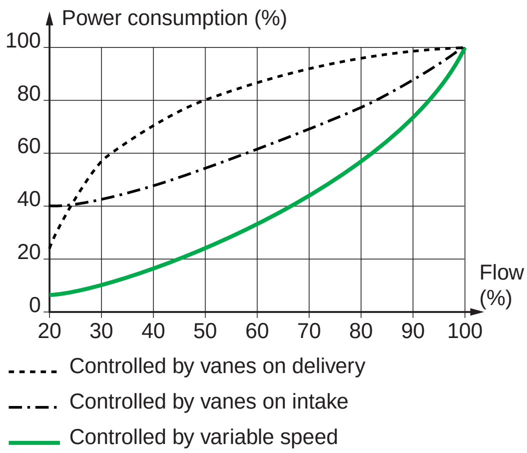


Fig. 16 : flow / power curves of a fan.

- energy savings are significant, and the system behavior in fact differs greatly with and without the variable speed drive, from nominal operation to maximum flow (see figure “flow / power curves of a fan”); thus, for a flow equal to 80% of nominal flow, the reduction in power consumption is 3% without a variable speed drive, but 50% with one;
- finally, modern variable speed drives equipped with filters eliminate the problem of the occurrence of harmonic currents upstream on the network.

Software can be used to calculate and evaluate precisely the savings made and the return on investment.

Therefore, for a fan driven by a 20 kW motor with a daily operating mode of:

- 2 hours at 100% flow,
- 6 hours at 80%,
- 4 hours at 50%,
- 12 hours at 20%,

Suppressing the upstream vanes control and adapting a variable speed drive significantly reduce energy consumption (cf. **fig. 17**). Return on investment is approximately 6 months.

	No drive	With drive	Savings
Active power (kWh / year)	126,600	55,700	**70,900**
Reactive power (kVARh / year)	78,450	0	**78,450**

Fig. 17 *: possible savings using a variable speed drive in a ventilation system (drive reference: ALTIVAR-Telemecanique ATV58HD28N4 with integrated line choke, source: Schneider Electric).*

6 Conclusion

Control of energy consumption has for a long time been a major source of concern for many countries – even for those which did not sign the Kyoto agreement – as a result of budgetary worries and a fear of shortages in particular due to:

- an operational electricity generation base which is insufficiently productive,
- an obsolete or ineffective electricity distribution system.

At a world level, this concern has continued to grow over recent years, and all the signs are that this situation will persist for some time.

In addition, to reduce CO_2 emissions and global warming, certain states have begun action which will probably be long term and extended to other countries. The pressure and incentives will continue to increase in many countries over the next decades.

Users on the other hand require reliable and constantly improved operation of their production facilities and comfort level in their buildings; at the same time they have to comply with national regulations and control their energy consumption costs.

Professionals in the field of energy distribution and management (design offices, system builders, service companies) are thus the first people concerned: they must develop highly innovative solutions and make them available to their customers, both during improvement work and when designing new buildings.

To do this, the most advanced manufacturers of electro-technical equipment, such as Schneider Electric, are developing ranges that integrate intelligence and communication to perform the functions required of them.

Finally, an appropriate energy audit is an essential stage in the search for energy saving in buildings to achieve genuinely optimized consumption.

Appendix: cogeneration

Cogeneration is defined as the combined generation of electrical and thermal energy from the same fuel source.

There are two different cogeneration concepts: the upstream cycle and the downstream cycle.

7.1 Upstream cycle

The first aim is the generation of electrical energy, with steam or hot water used as by-products of the process. For example, paper mills require electrical energy, steam and hot water in their process.

There are three usual applications:

■ Steam turbines: Fuel is burned to produce steam at high pressure which drives a turbo-alternator, with the turbine output used in the form of low pressure steam or hot water.

■ Gas turbines: A gas turbine is used to produce electricity and the exhaust gases (approximately 500°C) are directed towards a heat recovery exchanger which produces steam or hot water for use in the process (see **fig. 18**). This system is used in various industries, such as hospitals, airports, etc.

■ Diesel engines: A diesel engine drives an alternator and the engine cooling circuit is used to produce hot water for heating, for example for the water in a swimming pool.

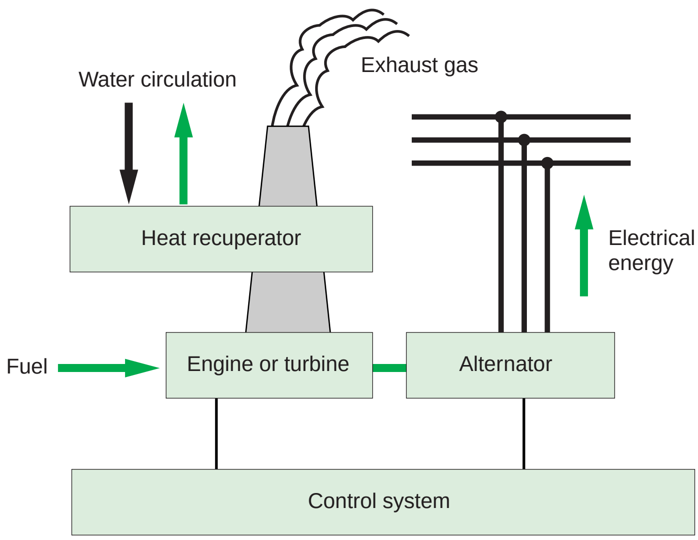


Fig. 18 : cogeneration: upstream cycle.

7.2 Downstream cycle

Electrical energy is generated using heat or hot gases which are by-products of a manufacturing process.
The relatively few examples occur in heavy industry (steelworks furnaces in particular). The hot exhaust gases are used to produce steam to power a turbine which drives an alternator (see **fig. 19**).
Electricity produced in this way is usually sold to a local distributor.

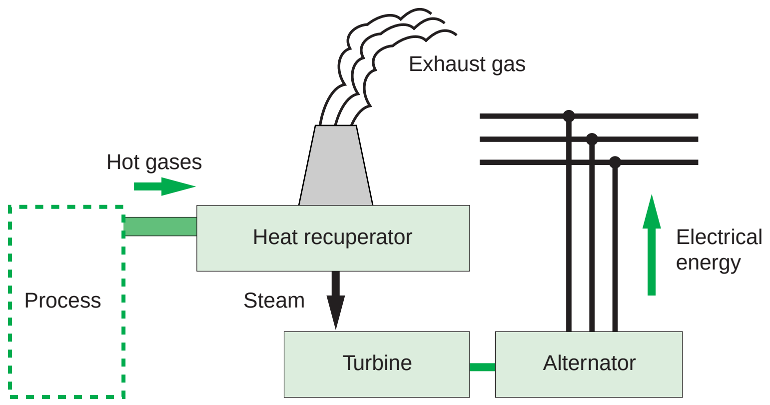


Fig. 19 : cogeneration: downstream cycle.

7.3 Advantages

Cogeneration systems are more efficient in their fuel use than separate systems, usually resulting in savings of up to 30% (see **fig. 20**). A wide variety of fuels can be used: natural gas, fuel oil, coal, wood, agricultural waste products (biomass) and household waste.

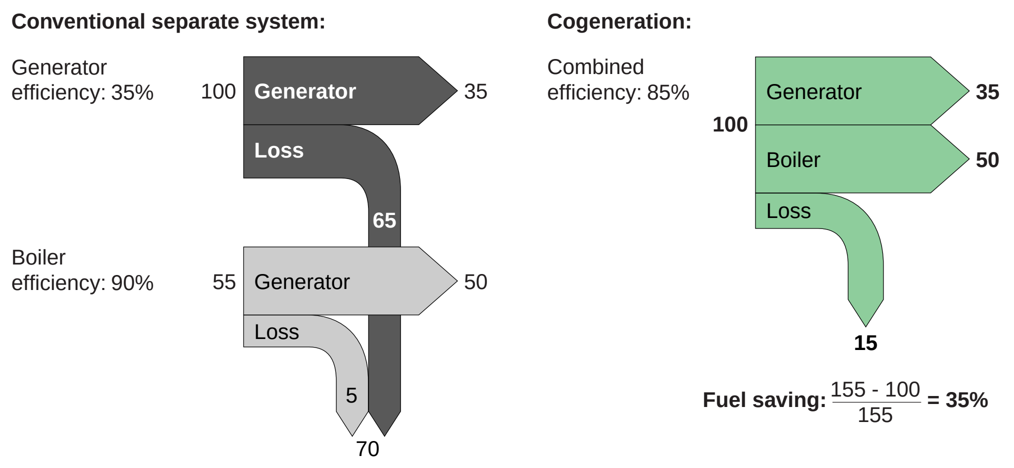


Fig. 20 : energy savings from cogeneration.

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