Power Quality Utilization Guide

Leonardo ENERGY

Hospitals

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Energy Efficiency

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Introduction to energy consumption in hospitals

This application guide describes the use of energy and the potential energy savings in the hospital sector, on the basis of theory and practical case studies. Hospitals represent some 6% of total energy consumption in the utility buildings sector. Utility buildings are offices, shops, hotels, restaurants, educational establishments and care institutions.
In order to analyse the energy consumption of a hospital in greater detail it is necessary to identify the larger energy consumers within the hospital.

Flows of energy within a hospital

The great majority of the energy used within a hospital is purchased from outside in the form of natural gas and electricity. A small proportion is bought in as diesel oil. The energy bought in is converted by a number of conversion systems into the most important internal flows of energy, namely heat, cold, electricity and compressed air. These energy flows are used for among others the following applications:

Heat is used in the form of steam and in the form of hot water. Steam is used for among others the kitchens, humidification in HVAC and sterilisation. In addition steam is used to transport heat over longer distances. Hot water is used in the form of central heating and tap water. In many cases heat is transported from the heat generating station in the form of steam and then converted locally into central heating or hot tap water. Gas-fired boilers or cogeneration systems generate the heat.

Electricity is used for a wide variety of purposes. The largest electricity consumers in a hospital are lighting, cooling machines, air compressors, circulation pumps, HVAC fans, medical equipment and office equipment.

Compressed air can be divided into two main categories, namely medical and technical air. Medical compressed air refers to direct treatment and care of patients. Examples include breathing apparatus and surgical tools driven by compressed air. Medical compressed air is subject to very high standards for availability and quality. Other compressed air that is not directly related to patients falls under the heading of technical compressed air. Examples include HVAC control systems, workshop applications or keeping containers under pressure.

Cold mainly takes the form of ice water and is used for the great majority in climate control systems, for cooling and drying the ventilation air.

In many cases cold is generated centrally by means of compression coolers. In combination with cogeneration, absorption-cooling machines are used to supplement compression coolers.

The breakdown of the energy flows just mentioned is shown in fig. 1 below.

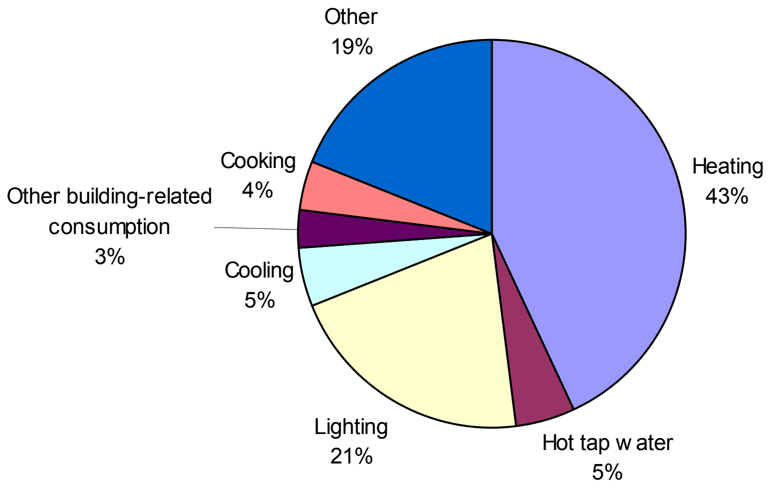

Figure 1. Energy balance in a hospital (source: ECN 2002)

Figure 1 shows that heating and lighting account for a large part of the energy consumption. Cooling and hot tap water each represent around 5% of the energy consumption. Electricity consumption by medical and office equipment falls into the “Other” category.

Benchmarking on the basis of energy consumption

The healthcare sector is one in which a lot of information is generally available concerning energy consumption. This offers many opportunities for energy benchmarking, i.e. comparing the energy consumption of different hospitals. The parameter used for comparison in benchmarking is very important. The two techniques most commonly used for benchmarking are the energy consumption per square meter or per bed. With regard to these techniques it is important to bear in mind that they are based on technical characteristics of the building. If sufficient data are available then it is desirable to compare hospitals on the basis of energy consumption both per bed and per square meter. One difficulty that stands in the way of benchmarking is the degree of outsourcing in the hospital: some hospitals contract out e.g. their catering or laundry activities, which off course leads to a lower energy consumption by the hospital itself.

A good example is provided by a medium-sized hospital for which a benchmarking study was carried out. The hospital was first compared on the basis of energy consumption per square meter, from which it turned out that from this point of view the energy consumption was higher than the average. From this it might be concluded that the hospital was underperforming. However, a second comparison on the basis of energy consumption per bed showed that the hospital performed better than average. The critical factor here is of course the number of square metres per bed. This factor is determined by the type of hospital and by the design criteria for its construction. We also have to take into account the trend towards higher quality of care and greater privacy for patients, which leads to a lower number of beds per room and thus a greater number of square metres per bed.

Both methods (per square metre or per bed) have their own particular disadvantages:

- In many countries the number of beds is taken as the basis for subsidies, so that sometimes we find highly creative ways of defining this parameter.
- When taking the number of square meters into consideration we have to decide which areas are included in the benchmark or not (e.g. car parks, corridors and equipment floors).

Another method of benchmarking is the one used in process industries, namely benchmarking on the basis of “production” by the hospital. The measure used for production may be the number of overnights or the number of bed-days. From this we can determine the energy consumption per overnight. However, this depends to a large degree on the type of hospital, and on trends in healthcare. For example, the number of overnights per treatment has fallen sharply in recent years, so that the number of treatments has risen considerably for the same number of beds.

Taking all these advantages and disadvantages into consideration, most authorities opt for benchmarking on the basis of the number of square metres, only with a distinction being made between teaching hospitals and local hospitals.

On the basis of sector studies, energy studies and data from research institutes, the average values for western Europe are as shown in table 1:

	Gas	Electricity
Energy consumption per m²	262 MWh/m$^{2/}$year	113 MWh/m$^{2/}$year
Energy consumption per bed	25 235 MWh/m$^{2/}$year	10 944 MWh/m$^{2/}$year

Table 1. Specific energy consumption by hospitals

Case studies

In the following chapters we look at a number of case studies for energy saving options. These are subdivided into the following areas:

- HVAC
- Compressed air
- Steam
- Lighting
- Cogeneration

For each of these areas we first give a general explanation, followed by some practical examples taken from various studies carried out in the Netherlands, Belgium and Germany.

In the calculations the following rates are used for gas and electricity:

- Gas price: 30 €/MWh
- Electricity price: 80 €/MWh

The profitability calculations are done on the basis of the energy savings achieved, without taking into account any government subsidies or maintenance savings that could further reduce the payback period, since government subsidies vary greatly from one country to the other.

The underlying formulas and calculations are not presented in this guide; only the results are given. Further details can be found in the application specific guides, issued in this series.

HVAC

For climate control of the various buildings and applications in a hospital there are usually various air conditioning units available, spread over the different parts of the building.

Depending on the application the air may be heated, cooled, humidified and/or filtered. Cooling, heating and humidification are generally done by a central generating station of heat and cold.

Some typical hospital applications and their particular characteristics include:

- Polyclinic and consultancy: used only during “office hours,” with HVAC to suit the comfort of people in these areas.
- Nursing wards: continuously occupied, with HVAC to suit the comfort of the people there.
- Laboratories, dialysis departments etc.: HVAC to control the conditions for the medicines and the tests carried out there.
- Operating theatres and emergency ward: continuously occupied, with HVAC to control the conditions within narrow limits of temperature and humidity. Ventilation and filtering systems are also used to prevent contamination.
- Administrative departments: used only during “office hours,” with HVAC to suit the comfort of people in these areas.

The most important areas that need to be conditioned in a hospital are of course the operating theatres. Separate HVAC units are used in this case, which moreover have to meet the particular regulations that apply (as regards smoothness of inside walls, ease of complete cleaning, etc.). Such an HVAC unit consists essentially of the following components:

- Fresh air intake section
- Coarse filtration
- Heat recovery unit
- Preheating unit
- Cooling unit
- After-heating unit
- Fan
- Moisturising
- Fine filtration
- Extraction section

The operating theatres themselves are generally fitted with a filter ceiling, i.e. the ceiling consists of a grid fitted with a high efficiency particulate air filter (HEPA) that ensures that no harmful particles are blown into the theatre.

The ventilation works on the downflow principle, with air being blown in from the ceiling at a specified speed directly above the operating table, where there is the most chance of contamination, so as to protect open wounds, surgical instruments etc.

Operating theatres are kept at overpressure with respect to neighbouring areas, so as to keep out dirt and contamination.

Most hospitals have several operating theatres, in which case there is usually one central air group that creates the overpressure, supplies fresh air and carries out basic air conditioning for all of them. In addition there is a separate HVAC unit for each operating theatre (or one for every two) that provides the specific conditioning for the required conditions.

The air extraction group is fitted with:

- Coarse filter
- Heat recovery unit
- Fan
- Extraction section

The energy consumption within an HVAC unit is accounted for by the following main applications:

- Heat, for heating the air
- Cold, for cooling and drying the air
- Electricity, to drive the fans
- Steam, to moisturise the air

The commonest energy saving measures for HVAC systems in hospitals are as follows (excluding building design considerations):

- Fitting frequency controllers on the fans
- Recovering heat from the extraction air
- Optimising the running hours
- Optimising the temperature and humidity

Case 1: Reducing the ventilation flow rate in a polyclinic during the night

Introduction

The hospital in this case is a medium-sized institution. There are various HVAC systems within the hospital, with several sub systems for each section of the building. The various HVAC systems are controlled by a building management system, with the HVAC parameters set according to the requirements of the different departments.

Present situation

The polyclinic has its own HVAC installation which operates 24 hours per day, 7 days per week. However, the polyclinic is not open 24/7, which means the HVAC system runs unnecessarily for some of the time.

Proposal

When the polyclinic is not in use, the air flow rate of the HVAC can be reduced to 50%. In theory the system could be switched off altogether, but for the purpose of this calculation a rate of 50% is assumed. It is further assumed that the HVAC system can operate at 50% for 9 hours per day, during which time the humidification can also be switched off.

Estimated savings & investment

The savings achieved are lower electricity consumption of the ventilation fans and lower gas consumption, since less air has to be warmed up and less steam is needed for humidification.

The HVAC settings are currently as follows:

Ventilation air supply rate	:	3 800 m^3/h
Temperature	:	17 ºC
Relative humidity	:	70 %
Ventilation operating hours	:	24 h/day

On the basis of the above parameters, the saving can be calculated as follows:

Period of reduced setting	:	9 h/day
Electricity consumption saving (ventilator fans)	:	10 MWh_e
Degree-hours on basis of 17°C (+1°C with respect to ventilator)	:	21 577 hK/a
Gas consumption saving (heating)	:	7.6 MWh_{th}
Number of humidification gram-hours	:	1 437 h/a*g/kg
Assumed efficiently of steam generation + transport	:	90 %
Gas consumption saving (steam)	:	5.1 MWh_{th}/year
Water savings (for information, not included in the calculation)	:	6.6 $m^{3/}$year

The annual energy savings amount to 10 MWh_e/year and 13 $MWh_{th/}$year, or a financial saving of € 1 190 per year. The required investment is nil.

Case 2: Heat recovery in an HVAC group

Introduction

The hospital in this case is a medium-sized institution. In the hospital there are various HVAC systems; most of them have heat recovery but some do not.

Present situation

At present there is no heat recovery from the extraction air in the office HVAC systems, which means that energy is lost unnecessarily. In the air ducts leading to and from the HVAC unit there is sufficient space to install heat recovery.

Proposal

A Twin-Coil heat recovery system could recover around 50% of the heat from the extraction air. The Twin-Coil system was chosen because of the practical feasibility of installing it in the existing air ducts.

Estimated savings & investment

The savings are achieved in terms of gas consumption, because less air needs to be heated due to the fact that some of the pulsed air is heated using heat from the extraction air. On the other hand the amount of electrical power consumed is higher, since fitting a Twin-Coil creates additional resistance in the air duct which has to be overcome by the fans.

The HVAC settings are currently as follows:

Ventilation air supply rate	: 10 500 m^3/hour
Temperature	: 18 ºC
Relative humidity	: 55 %
Ventilation operating hours	: 18 h/day

On the basis of the above parameters, the saving can be calculated as follows:

Present gas consumption (heating)	: 170 MWh_{th}
Degree-hours on basis of 18°C (+1°C with respect to	: 42 950 hK/year
Efficiency of Twin-Coil heat exchanger	: 50 %
Gas consumption saving (heating)	: 85 MWh_{th}
Additional electricity consumption (fans)	: 4 MWh_e

The annual energy savings amount to -4 MWh_e/year and 85 $MWh_{th/}$year, or a financial saving of € 2 230 per year.
The investments comprise installation of a Twin-Coil heat recovery unit in the air ducts leading to and from the HVAC unit. The estimated amount of the investment is € 15 000, resulting in a payback time of 6.7 years.

Compressed air

Compressed air is an essential form of energy for a hospital. Depending on the requirements it can be divided into medical and technical compressed air.

Medical compressed air

Medical compressed air has many uses in a hospital. Examples include assisted respiration for patients and driving surgical tools. Very strict requirements are imposed, not only on the compressed air itself but also on the equipment used for producing it. Some important legal requirements are as follows:

- Production equipment must be redundant: if one compressor fails another must be able to meet the entire demand.
- Conditioning equipment must also be redundant.
- The air must be clean, tasteless and odourless.
- The system must be designed so that maintenance can be performed without compromising the redundancy.
- Other legal requirements are laid down by standard EN-12021.

In practical terms the pressure of the compressed air is another important factor. For surgical tools driven by compressed air a pressure of around 10 bar is frequently required. Since the compressed air installation is already complex and costly because of the legal requirements, in many cases all the medical compressed air is produced at 10 bar, although such a high pressure is only needed for the surgical instruments. Therefore it is important to realise that reducing the compressed air pressure by 1 bar yields an energy saving of around 6%.

Technical compressed air

Technical compressed air comprises all the other applications that do not have to meet the very strict requirements for medical compressed air. As such it is comparable with the compressed air found in industry, and is used for among other things to activate the HVAC control elements (valves and louvers), for workshop applications and keeping containers under pressure.
The temperature required for technical compressed air is 5 or 6 bar lower than for medical compressed air. From the energy point of view, it is desirable to make a distinction between medical and technical compressed air. In practice, however, it frequently happens that the systems are not separate, due to the relatively low consumption of compressed air and the complexity of the compressed air installations. The following practical example looks at the advantages to be gained from separating the compressed air systems.

Case 1: Splitting up the compressed air network and using a frequency controlled compressor

Introduction

The hospital in this case is a medium-sized institution that uses both medical and technical compressed air.

Present situation

The present compressed air installation comprises three compressors of 37 kW each. These compressors produce all the compressed air, without any splitting up into medical and technical. The surgical instruments require a pressure of 11 bar, so that all the compressed air – both medical and technical – is produced at this pressure. The air is dried by absorption drying.
The compressors make use of ON/OFF regulation, without any frequency regulation. The percentage of time at zero load is 45% on average. At zero load the compressors do not produce any compressed air, but they continue to consume up to 25% of their rated power.
For the purposes of this case study the following consumption figures are used:

- Annual consumption of medical compressed air : 142 000 Nm^3/year
- Annual consumption of technical compressed air : 820 000 Nm^3/year

Proposal

By splitting the compressed air network into medical and technical compressed air the technical part can be produced at a lower pressure of 6 bar, with lower quality requirements. It was also proposed to install an additional two compressors (one for each network), with frequency regulation, thus reducing the zero load consumption to a minimum. Two of the present compressors were to be kept as a backup for the medical compressed air, in order to ensure the necessary redundancy. The third compressor was to be used to provide the baseload for the technical compressed air, with the frequency-controlled compressor dealing with the variations in compressed air consumption.

Estimated savings & investment

The savings were achieved by lowering the pressure, reducing the energy consumption at zero load and making savings on drying and cleaning the technical compressed air. The savings were calculated as follows:

Lowering the pressure of the technical compressed air:

Annual consumption of technical compressed air	:	820 000 Nm^3/year
Specific energy consumption at 11 bar	:	0.158 kWh/Nm^3
Specific energy consumption at 6 bar	:	0.107 kWh/Nm^3
Energy saving achieved by lowering the pressure	:	42 MWh/year

Installing compressors with frequency regulation:

Zero-load energy consumption with respect to total consumption	:	25 %
Consumption savings for 11 bar network at zero load	:	5.5 MWh/year
Consumption savings for 6 bar network at zero load	:	21.5 MWh/year
Total energy saving achieved by frequency regulation	:	27 MWh/year

Savings on compressed air treatment:

Total energy consumption for compressed air	:	152 MWh/year
Energy consumption of absorption air drying, as a percentage of the total compressed air energy consumption	:	25 %
Energy consumption of standard air drying, as a percentage of the total compressed air energy consumption	:	5 %
Present energy consumption for drying	:	30.5 MWh/year
New energy consumption for drying of the 11 bar network	:	5.6 MWh/year
New energy consumption for drying of the 6 bar net-	:	4.4 MWh/year
Energy saving	:	20.5 MWh/year

The annual energy savings amount to 90 MWh/year, or a financial saving of € 7 200 per year.

The investments comprise the purchase of two frequency regulated compressors of 12.5 and 37 kW respectively, purchase of a drier for the technical compressed air and making modifications to the compressed air network. The estimated amount of the investment is € 40 000, resulting in a payback time of 5.5 years.

Steam

Steam is used a great deal in hospitals: it permits high energy densities and enables large amounts of energy to be moved around easily.
Steam can easily be generated from water, which is present everywhere in large quantities. Furthermore, steam installations are relatively easy to regulate. Steam is used for many applications in hospitals, including sterilisation, humidification, heating and providing hot tap water. Note however that heating with steam is not always the best solution, as a heating system (decentralised or otherwise) that operates at lower temperature is more suitable for space heating.
For generating and distributing steam it is important to observe the following rules of thumb.

<u>Ensure good pipe insulation.</u> The losses from an uninsulated pipe are huge. Fittings such as valves and flanges must also be well insulated. By way of illustration, an uninsulated DN125 valve at a temperature of 175°C has a heat loss of 670 W, or an annual energy loss of 5.9 MWh.

<u>Condensate return pipes</u> must also be well insulated. The hotter the condensate is returned to the boiler, the lower the energy consumption. Each 6°C increase in temperature of the condensate yields an energy saving of 1%.

<u>Steam leaks</u> must be limited as far as possible. A steam leak with a diameter of 3 mm in a system at a pressure of 10 bar loses 36 kg of steam per hour.

<u>Flue gas losses</u> must be kept as low as possible. This is done by keeping the flue gas temperature as low as possible. Heat recovery from flue gases can be done in various ways, as shown in fig. 2 below.

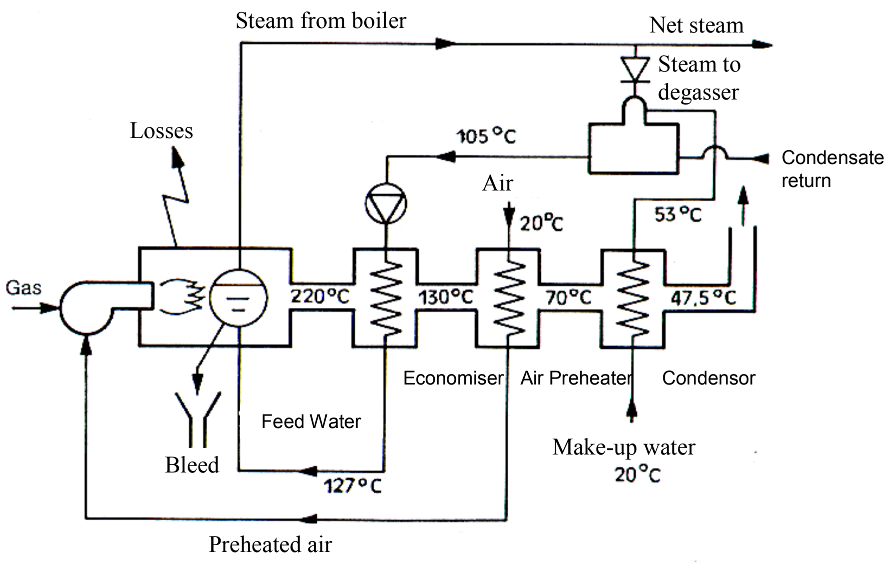

Figure 2. Possibilities for recovering heat from a boiler

Various points also have to be observed when it comes to the steam consumers:

Steam humidification in air conditioning systems is a large consumer of steam. Here it is important to ensure that steam humidification is not operated unnecessarily, for example when the department is closed or when there is sufficient moisture in the outside air. Also, the humidification unit must not be set too high. A relative humidity of 30% counts as the minimum for comfort.

Hot tap water is frequently produced by means of a TSA (tank system assembly). From the point of view of energy, however, it is more efficient to produce the hot tap water from a directly fired condensing boiler, as such a boiler has a higher efficiency than the steam circuit; producing hot water by means of steam means first generating high-grade heat in the form of steam and then converting it into low-grade heat in the form of hot tap water.

Space heating should preferably be done using a directly fired boiler instead of steam, for the same reason. However, this technique is already used in many cases.

Sterilisation is an important consumer of steam. The high temperature and penetrating power of steam make it a suitable method of sterilisation. However, for some applications electrical sterilisation is also possible, and this is more efficient from an energy point of view.

Case 1: Switching off the steam humidification in summer

Introduction

The hospital in this case is a medium-sized institution with central steam generation. The steam generating system is 30 to 40 years old and has low efficiency. Steam is also purchased from outside.

Present situation

In the present situation the steam humidification continues to operate during the summer, although there is sufficient moisture in the outside air to meet the requirements. This means that the steam pipe network is also kept up to temperature during the summer.

Proposal

The steam humidification can be switched off whenever the air humidity is high enough in summer. On the basis of the number of humidification gram-hours, it should be possible to shut down the entire steam pipe circuit during the four summer months.

Estimated savings & investment

The savings are achieved in terms of steam consumption for humidification and lower losses in the steam circuit (e.g. insulation losses).

From the consumption data it appears that the steam consumption for keeping the system hot during the proposed four summer months is 150 tonnes.
On the basis of a steam cost of 61 euros/tonne, the annual energy saving is € 9 150. The investment required for this measure is nil.

Case 2: Hot tap water production by means of a directly fired boiler

Introduction

The hospital in this case is a medium-sized institution, with steam generated centrally by means of two boilers.

Present situation

The hot tap water is currently produced by means of steam from the two boilers, together with another two water heaters. The hot tap water consumption is around 100 m³ per week.

Proposal

Steam is a very expensive form of energy. In the present situation the steam is first generated at a high temperature and then used to heat water to a temperature of 70°C. It is more efficient to produce hot tap water by means of a directly fired boiler. This method also avoids the losses that occur during steam generation and transport.

Estimated savings & investment

The savings are achieved in terms of the efficiency of the hot water generation. The efficiency of a directly fired boiler is higher than that of a steam boiler and the associated steam transport efficiency.

The savings are determined as follows:

Hot water consumption	: 100 m^3/week
Hot water temperature	: 70 °C
Water supply temperature	: 10 °C
Estimated efficiency of steam circuit (boiler + transport)	: 81%
Present energy consumption per year for hot water	: 450 MWh/year
Efficiency of directly fired condensing boiler	: 98 %
Energy savings per year	: 78 MWh/year

The annual energy saving amounts to 78 MWh/year, or a financial saving of € 2 340 per year. The estimated amount of the investment is € 10 500, resulting in a payback time of 4.5 years. The investment is based on a new HR boiler, gas pipe and exhaust flue.

Lighting

Lighting is one of the large energy consumers in hospitals, just as in many other kinds of utility buildings. Various studies have shown that some 20% of the total energy consumption in a hospital is accounted for by the lighting installation. When it comes to the energy savings that can be made on lighting, these can be divided into two main categories, each of which is discussed below.

Smart switching

The fastest savings can be achieved with "smart switching" of the lighting. Lighting is frequently switched on unnecessarily when e.g. there is sufficient daylight or there is nobody in the room. With hand operated systems especially, lights tend to be left burning needlessly. The advice is therefore to make the greatest possible use of automatic light regulating equipment. Examples include:

- Daylight sensors
- Presence sensors
- Connection to the building management system (BMS)
- Timers

Efficient lighting

Fluorescent tube lighting (TL) is used a great deal in hospitals. Fluorescent tubes are not only efficient but also provide a good quality of light. Semi-conductor light sources or LED's are expected to be even more efficient than fluorescent tubes in future, but at the moment fluorescent tubes still reign supreme in tends of light colour, colour preservation and efficiency.

Apart from the light source itself there are two important factors that influence the energy consumption of a lighting installation.

The first is the ballast or ballast used for the fluorescent tubes. There are two types of ballast: magnetic and electronic. Magnetic ballasts have the disadvantage that a large amount of energy is lost in the ballast itself, as much as 20% of the energy consumption of the light source. For a 58 W fluorescent tube, this means that about 13 W is lost in the ballast. Electronic ballasts on the other hand have losses of only 1 or 2%. Magnetic ballasts still tend to be used widely in hospitals that are more than 5 or 10 years old.

The second factor that influences the energy consumption is the light fitting, in particular the optics, with the degree of reflectivity of the optics playing an important role. The higher the reflectivity of the fitting, the higher the light emission and the greater the efficiency.

Examples of these are given in the following case study.

Case 1: Replacing conventional magnetic ballasts

Introduction

The hospital in this case is a medium-sized institution with most of the lighting consisting of fluorescent tubes. However, there is no overview of the total energy consumption of the lighting. This makes it difficult to arrive at a precise calculation, but the potential savings can nevertheless be estimated on the basis of reference data.

Present situation

An estimated 70% or so of the lighting is currently equipped with obsolete, conventional magnetic ballasts. As already explained, such magnetic ballasts are responsible for considerable energy losses (around 20%).

Proposal

By using energy-efficient light fittings with electronic ballasts, the ballast losses can be reduced and energy can be saved on the lighting.

Estimated savings & investment

There is no overview of the number of lighting fittings or the energy consumption of the lighting installation. However, based on data from previous studies and from the literature it is estimated that in an average hospital lighting accounts for some 20% of the total energy consumption. For the hospital in the case study this means that some 2 400 MWh of the annual electricity consumption is due to lighting. This value was first verified on the basis of the total floor area, by determining the installed power per m² per 100 lux, which confirmed the estimate. The savings potential was then calculated as follows:
The percentage of conventional fluorescent lighting fittings with conventional ballasts is around 70%. It was further assumed that 90% of the total lighting consists of fluorescent tubes. The majority of the fittings have white enamelled reflectors.

Total energy consumption of the lighting	: 2 400 MWh/year
Power consumed by fluorescent tube lighting (90%)	: 2 160 MWh/year
Losses in conventional ballasts	: 20 %
Percentage of light sources with conventional ballasts	: 70 %
Estimated number of fluorescent light sources with conventional ballasts, on the basis of 58 W per tube	: 4 000
Total energy consumption of conventional fluorescent lights	: 1 780 MWh/year
Potential savings by fitting electronic ballasts and efficient optics	: 26 %
Total savings potential	: 462 MWh/year

The annual energy savings amount to 462 MWh/year, or a financial saving of € 37 000 per year. From this it can be seen that considerable savings can be made on lighting, although the investment costs are very high. If the investments have to be repaid solely on the basis of the lower energy consumption, then we arrive at a payback time of between 6 and 9 years, assuming that the existing light fittings are replaced by new ones.

Cogeneration

Cogeneration is combined generation of heat and electricity. The advantage of cogeneration is that it enables the heat released by electricity generation to be used. The most well-known form of cogeneration is an electricity generator powered by an internal combustion engine, with the heat released by the engine being used to produce steam and/or hot water. An important factor for the economic potential is that good use has to be made not only of the electricity but also of the heat. This means that there has to be a continuous demand for heat as well as electricity.

Because of their specific heat and electricity consumption, hospitals are particularly suitable for cogeneration. A characteristic of hospitals is that there is a constant demand for heat all year round, for e.g. hot tap water and sterilisation. This constant heat demand profile has a favourable effect on the number of hours at which the cogeneration unit can operate at full load. Examples of the heat and electricity demand profiles of a hospital are shown in the figures below.

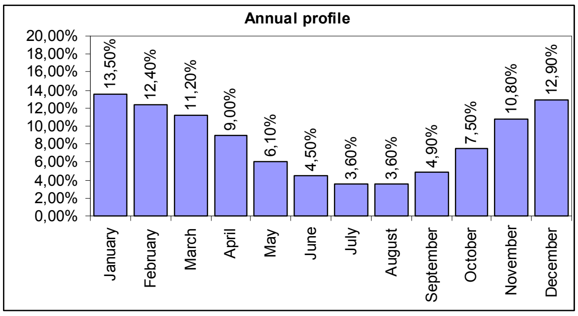

Figure 3. Annual profile for heat demand

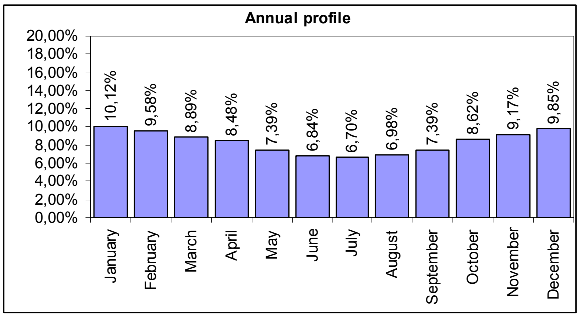

Figure 4. Annual profile for electricity demand

In practice a cogeneration unit is frequently combined with an absorption cooling machine in order to raise the number of hours at full load in the summer. Note however that it is important to make use of the absorption cooling machine in the correct way, as shown in the calculation examples below.

A further advantage of a cogeneration unit is that it acts as a backup power supply, thus contributing at least part of the necessary continuity of operation in case of a grid power failure; a cogeneration unit can take over part of the work of an emergency generator.

When installing a cogeneration unit there a number of important factors that have to be taken into consideration. These are illustrated in the following calculation examples.

Calculation example for a cogeneration installation

In this calculation example a number of practical considerations are examined in more detail. We first look at the costs of the energy generated by the cogen unit.

Electrical efficiency of cogen unit	: 35 %
Thermal efficiency of cogen unit	: 50 %
Gas price	: 30 €/MWh
Price per MWh of electricity (from cogen, without using the heat)	: 85 €/MWh
Price per MWh of thermal energy (from cogen, without using the electricity)	: 60 €/MWh
Cost of buying electricity from outside (peak)	: 80 €/MWh
Cost of buying electricity from outside (off-peak)	: 45 €/MWh
Cost of thermal energy from gas-fired boiler (eff=90%)	: 33 €/MWh

From the above data there is clearly no point in depending on the cogen unit only for electricity or only for thermal energy. A number of calculation examples are shown below, based on the above data.

Cogeneration operating during the day and during the night

The differences between peak and off-peak prices for electricity have a strong influence on the cost savings that can be achieved with cogeneration. For the sake of example we will assume that 100 MWh of electricity is produced during the day and that good use can be made of the heat.

During the day:

Electricity produced	: 100 MWh_e
Heat produced	: 143 MWh_{th}
Cost of electricity + heat produced	: 8 570 €

In this case 100 MWh_e and 150MWh_{th} cost € 8 570. If this quantity of energy had been purchased from outside during the day the cost would have been as follows:

Purchase price for 100 MWh_e	: 8 000 €
Purchase price for 143 MWh_{th} (gas)	: 4 760 €
Total purchase price	: 12 760 €
Cost saving due to cogen	: 4 190 €

If the same quantity had been purchased from outside during the night the calculation is as follows:

Purchase price for 100 MWh_e	: 4 500 €
Purchase price for 150 MWh_{th}	: 5 000 €
Total purchase price	: 9 500 €
Cost saving due to cogen	: 930 €

From this we can conclude that the cost savings achieved by cogeneration depends to a large extent on the energy prices and whether good use can be made of the heat produced.
The electricity demand for a hospital is so high that in most cases there is never any surplus. But even if there is a surplus it can be sold back to the grid. For this reason it is important for the cogeneration to be operated on the basis of the demand for heat.

Cogeneration in combination with an absorption cooling machine

In the example below the cogen unit is operated in combination with an absorption cooling machine. In addition to the absorption machine a number of compression cooling machines are also available. The demand for cold amounts to 500 MWh_{th}. The absorption cooling machine has an efficiency of 70%. The absorption cooling machine is operated whenever the heat demand of the hospital is lower than the heat supplied by the cogen unit.

Amount of demand for cold	: 500 MWh_{th}
Efficiency of absorption cooling machine	: 70 %
Heat demand for absorption cooling machine	: 715 MWh_{th}
Amount of electricity produced (for 715 MWh_{th})	: 500 MWh_e
Total cost for 500 MWh of cold and 500 MWh of electricity	: 42 900 €

If the cold required during the day was produced by the compression cooling machines, the costs would be as follows, with the 500 MWh of electricity being bought in from outside:

COP compression cooling	: 3.5
Electricity consumption by compression cooling machine to produce 500 MWh_{th} of cold	: 143 MWh_e
Cost of 500 MWh_{th} of cold	: 11 430 €
Cost of 500 MWh_e of electricity	: 40 000 €
Total cost for 500 MWh_{th} of cold + 500 MWh_e of electricity	: 51 430 €
Cost saving	: 8 530 €

From this we conclude that the absorption cooling machine can usefully supplement the cogeneration during the day, if the demand for heat is low.

If we look at the same situation during the night the calculation is as follows:

COP compression cooling	: 3,5
Electricity consumption by compression cooling machine to produce 500 MWh_{th} of cold	: 143 MWh_e
Cost of 500 MWh_{th} of cold	: 6 435 €
Cost of 500 MWh_e of electricity	: 22 500 €
Total cost for 500 MWh_{th} of cold + 500 MWh_e of electricity	: 28 935 €
Cost saving	: -13 950 €

From this we conclude that it does not make sense for the cogen to produce extra heat at night for the absorption cooling machine. Because of the low price for off-peak electricity, it is better for the cold to be produced by the compression cooling machines. During the night the cogen would only produce the heat that can usefully be employed, with the cogen being controlled according to the heat demand from the hospital.