Sauter FM GmbH
Werner-Haas-Str. 10
86193 Augsburg
Tel. 0049 821 906730

Energy analysis
and
energy-saving suggestions
for the
Westpfalzklinikum Kaiserslautern

Sauter FM GmbH
Werner-Haas-Str. 10
86193 Augsburg
Tel. 0049 821 906730

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Sauter FM GmbH
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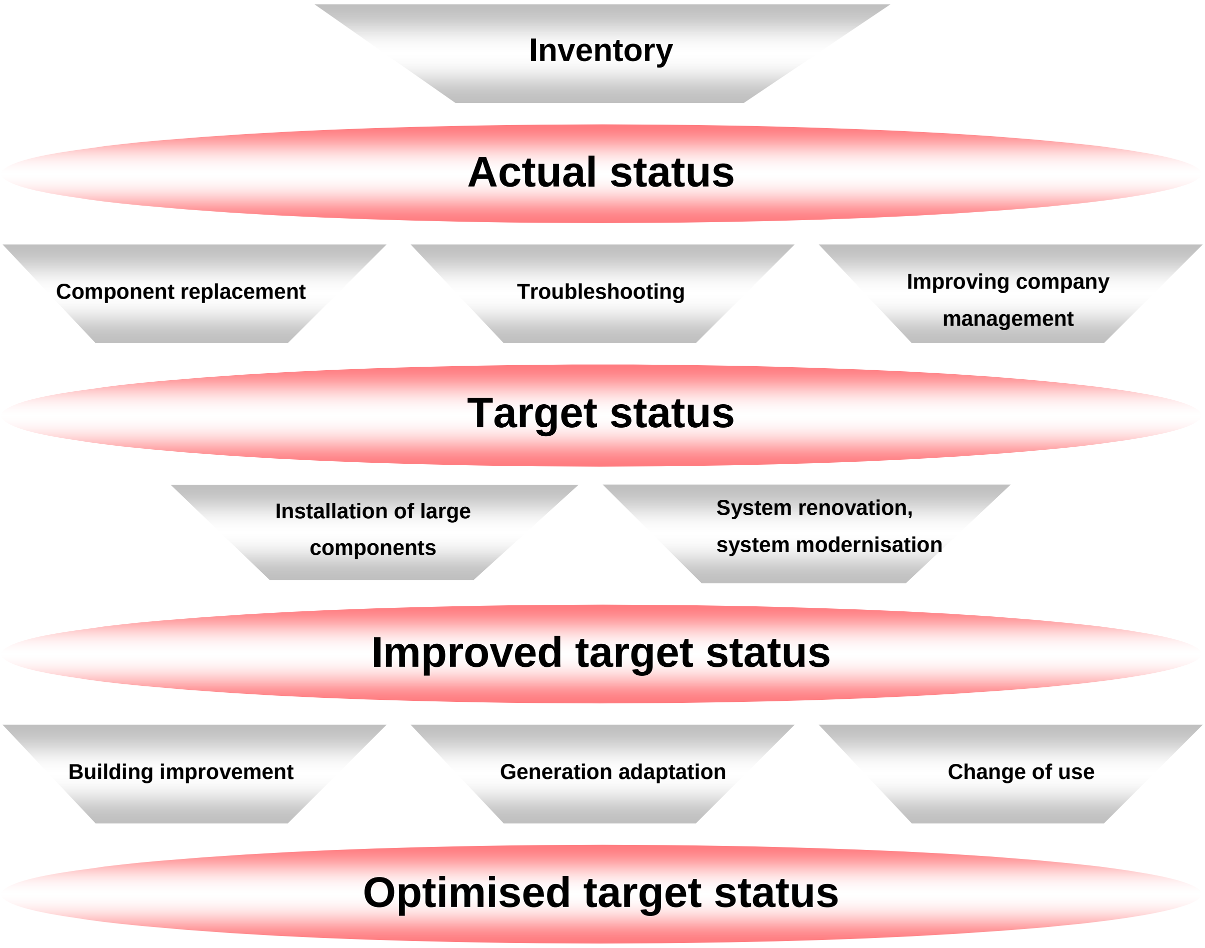
86193 Augsburg
Tel. 0049 821 906730

1 Introduction

The increasing pressure to reduce costs in the health service and the increase in general operating costs are forcing hospital administrations to exploit all cost-cutting options. The hospital financing law also obliges operators to run their facilities at low cost. The supply of energy represents a significant proportion of the operating costs. Sauter is working out long-term cost-cutting proposals for the *Westpfalzklinikum* ('Westpfalz Clinic') in Kaiserslautern for the district heat, steam, electricity and water/sewage supply media.
The main focus of the energy analysis is on system technology, specificially:

- **Compound heat-generating plant**
- **Measuring technology**
- **Energy controlling, monitoring**
- District heating systems
- Steam systems
- Air-conditioning systems
- Cooling
- Lighting
- Building management systems

In order to provide a cost-effective energy supply and low consumption, Sauter is offering joint collaboration to the Westpfalzklinikum, the stations of which are shown in the following diagram:



Sauter takes the following into consideration in everything that it does:

- Strict regulations:
    - Hygiene
    - Air quality
    - Room temperature
    - Noise protection
- Good supply reliability
- Patient satisfaction

2 System technology

2.1 Compound heat-generating plants

Examples of previous successes have shown that hospitals from a certain size (200 beds) are almost predestined for the use of compound heat-generating plants because of their specific heat and electricity consumption structure. Compound heat-generating plants are based on the technical principle of power/heat coupling, i.e. the simultaneous provision of electricity and heat. A compound heat-generating plant consists of a conventional combustion engine that drives a generator to generate electricity. The waste heat from the engine and the exhaust can be used for heating and generating domestic hot water. Absorption cooling units can also be powered using waste heat, which is particularly beneficial in summer as less heat is needed at this time of year.

Natural gas is used as fuel in the majority of cases. However, oil or bio-gas can also be used instead of natural gas. Oil has the disadvantage that large quantities thereof have to be held in tanks because of the long operating time of the compound heat-generating plant, or the tanks have to be topped up at frequent intervals. The oil price is also subject to major fluctuations, and the high price increases in recent years have cast a shadow over the cost-effectiveness of using oil for heating in the future.

The following circumstances speak in favour of using of a compound heat-generating plant:

- Simultaneous heat and electricity requirement
- Consistent electricity requirement over the course of the year
- Practically constant basic current load
- Heat needed to prepare hot water all year round
- Continuous cooling requirement

The electrical energy load trend for one day in the biggest building in the hospital (the ward block) is shown in Figure 1: Electrical energy load
as an example.

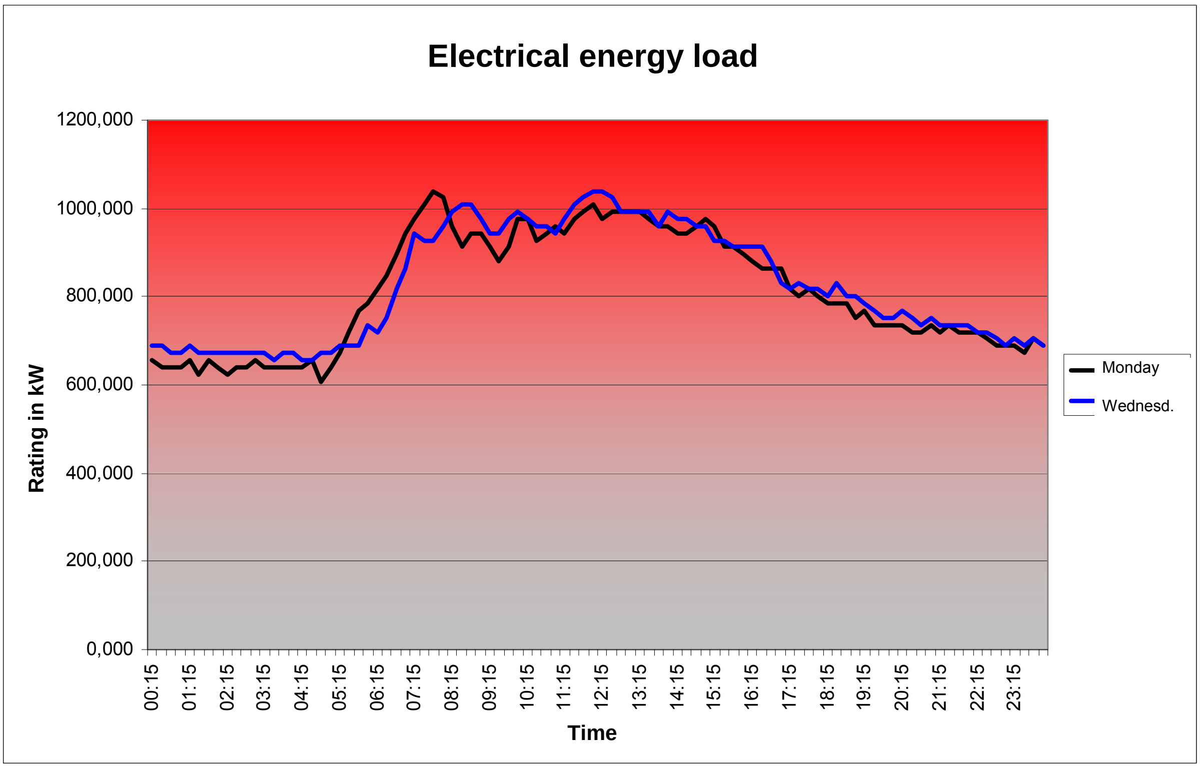


Figure 1: Electrical energy load

The basic load is approximately 600 kW. The total basic load of the entire ward block is about 1300 kW, and the peak load is 1900 kW.

The following cost-effectiveness consideration is intended to determine the approximate cost savings that could be achieved by using a compound heat-generating plant with an electrical output of 500 kW.

Compound heat-generating plant data		
Generator output	500,00	kW
Thermal output	700	kW
Power coefficient	0.71	[-]
Electrical efficiency	0.36	[-]
Heat utilisation factor	1.00	[-]
Maximum fuel capacity/fuel usage	1400	kW
Full load hours	5000	Bh/a
Property data		
Annual heat generation usage level	90%	
Estimated fuel consumption for property	18,730,928	kWh/a

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Estimated power consumption for property	10,920,111	kWh/a
Generated boiler heating energy	16,857,835	kWh/a
Electrical output (peak output)	900	kW
Prices		
Fuel price including mineral oil tax and eco-tax	0.03000	EUR/kWh
Mineral oil tax, gas	0.05500	EUR/m³
Heating price = capital+consumption+operation	0.05285	EUR/kWh
Unit price	100	EUR/kW*a
Demand price (average HAT/NT) EXCLUDING current rate of electricity tax	0.10000	EUR/kWh
Electricity tax rate over usage period	0.02050	EUR/kWh
"EEG and KWKG" (Renewable Energy Sources Act and Combined Heat and Power Act) tax proportion of purchased electricity	0.00540	EUR/kWh
Total electricity price	0.12590	EUR/kWh
Heat/cost balance		
Investment costs	520,000	EUR
Cost of heating energy, boiler without compound heat-generating plant	890,953	EUR/a
Heating energy generated by compound heat-generating plant	3,500,000	kWh/a
Residual heat from heating boiler	13,357,835	kWh/a
Residual heat costs	705,975	EUR/a
Cost of mains-supplied kilowatt hours without compound heat-generating boiler	1,374,842	EUR/a
Kilowatt hours generated by compound heat-generating plant	2,500,000	kWh/a
Residual volume obtained from mains with compound heat-generating plant	8,420,111	kWh/a
Residual costs, mains-supplied kilowatt hours	1,060,092	EUR/a
Basic charge for mains-supplied power	90,000	EUR/a
Assumed availability of compound heat-generating plant electricity output	0.70	[-]
Minus compound heat-generating plant electricity output, assumed availability	350	kW
Residual volume obtained from mains with compound heat-generating plant	550	kW
Residual costs, mains-supplied power with compound heat-generating plant	55,000	EUR/a
Power price cost saving	35,000	EUR/a
Compound heat-generating plant fuel consumption	7,000,000	kWh/a
Compound heat-generating plant fuel consumption costs	171,500	EUR/a
Costs without compound heat-generating plant	2,355,795	EUR/a
Residual costs with compound heat-generating plant	1,992,567	EUR/a
Operational costs (maintenance + repair)		
Compound heat-generating plant maintenance costs incl. repairs and oil	8.000	EUR/Bh
Annual maintenance costs (including general overhaul at 7000 annual operating hours, AOH)	40,000	EUR/a
Savings		
Reduced consumption costs	363,229	EUR/a
Additional operating costs	-40,000	EUR/a
Annual saving	323,229	EUR/a

The performance data, the estimated investment costs and the approximate cost saving for other compound heat-generating plant sizes are shown in the following table.

Compound heat-generating plant variant	I	II	III	IV
Electrical output in kW	500	400	339,83	234,43
Thermal output in kW	750	560	481	363
Fuel output, gas in kW	1500	1100	934	667
Full load hours in AOH	5000	5000	5000	5000
Investment costs in EUR	520,000 €	380,000 €	290,000 €	210,000 €
Saving in EUR/year	**323,229 €**	**267,033 €**	**231,033 €**	**164,831 €**

A compound heat-generating plant has other advantages in addition to reducing energy costs:

- Utilisation of waste heat in summer for generating cooling with absorption refrigeration units
- Emergency power supply
- Better heat supply reliability

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2.2 Air-conditioning systems

Structural changes, shutdowns and the addition of new facilities can change the parameter requirements for temperature, humidity and minimum air exchange – with serious consequences for plant engineering. For this reason, many air-conditioning systems are currently being scrapped and replaced with modern systems that meet the new requirements. The new systems promise to provide energy-efficient operation through:

- Fans with speed control
- Circulated air operation
- Heat recovery
- Free cooling
- Optimised air flow in the zones
- Duct networks with low pressure loss
- System concept (quantity, type and arrangement of components) adapted to usage requirements
- Optimised control strategy:
    - Presence switches
    - CO_2-controlled air quantity adjustment
    - DDC technology: time programs
    - h,x-guided control
    - Condition of room air controlled in accordance with comfort level

Sauter is checking the following energy saving strategies for existing IAQ systems:

- Frequency converter retrofitting
- Adaptation of time programs to operating time
- Air volume reduction, e.g. in the event of a change of use
- Control system modifications

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The following example calculation shows the considerable savings achieved by adapting the time programs.

Ventilator output	30 kW
Previous operating time:	5.00 am - 01.00 am
New operating time:	5.00 am - 11.00 pm
Operating time reduction	2 hours
Annual operating days	365 days
Electricity price	10 Cents/kWh
Savings	2190 Euros per year

Adapting the time programs also makes it possible to reduce the heating and cooling costs for air treatment.

Other recommended optimisation measures are:

- Installation of heat recovery systems
- Checking whether recirculating air operation is possible
- Reducing the room climate parameter requirements (where possible)
- Filter monitoring and replacement at the right time
- Use of cooling by means of humidification (adiabatic cooling)
- Checking the operation of butterfly valves and regulating valves

The following estimation shows the potential savings that can be made in large air-conditioning plants by means of regular filter replacement.

Volume flow	40,000 m³/h
Ventilator efficiency level	60%
Pressure loss with irregular filter replacement	850 Pa
Pressure loss with regular filter replacement	700 Pa
Difference	150 Pa
Electricity kilowatt hour rate	10 Cents/kWh
Daily operating time	17 hours
Savings	1724 EUR per year

2.3 Heating

2.3.1 Generation, provision

Almost all of the heating in the hospital is in the form of district heating and steam supplied by the municipal provider. Only a few buildings are heated with gas. Converting heating networks from steam to hot water led to high energy savings and cost reductions. The reasons for this are:

- The system temperatures are significantly lower, resulting in less heat loss
- There is no longer any need for expensive maintenance, monitoring and testing of safety and control systems for steam networks

Other cost reductions may be possible in the basic cost of district heating.
The basic cost of district heating results from the product of the power price (in Euros per kW) and the connected load (in kW). The connected load is set by the district heating provider via a volume flow limiter and can be reduced by:

- Increasing the temperature difference of heating water
- Using heat accumulators to flatten out peak loads
- Starting up heat consumers at staggered times

A greater temperature difference can be achieved by:

- Using hydraulic circuits that are compatible with district heating systems (circuits in which no flow water directly enters the return, as is the case with diversion circuits and injection circuits, for example)
- Avoiding hydraulic heat-reclaim units
- Avoiding overflow valves
- Large-area heating systems such as underfloor heating and concrete-core temperature control systems
- Return cooling (hot return from ventilation systems for pre-heating domestic hot water)

Measuring the return temperature at the primary side (district heating) makes it possible to establish how district heating water is utilised with regard to energy. High return temperatures mean that only a little heat is removed from the flow of district heating water. The return temperature measurements can be stored over a long period with the building management system, allowing statements to be made about the operational characteristics of the heating networks.

Modern heat counters can also be used in conjunction with a building management system to record the heat load over a long period, see Figure 2

The graphical display of the load trend allows the connected load to be accurately adapted.

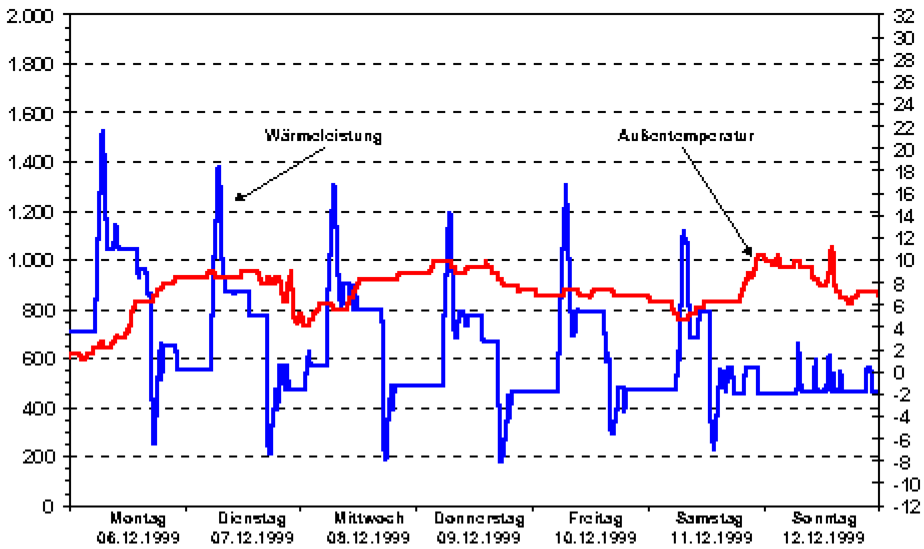

Figure 2

If the connected load is reduced, it is essential to pay attention to the following points:

- The connected load can be reduced only to the extent that no loss of thermal well-being occurs (longer warm-up times)
- The hospital is going to be extended in the future. The connected load is therefore likely to increase.
- More power reserves must be planned for a hospital, as it is important to have a reliable supply in these buildings.

2.3.2 Distribution

The heating water distribution system consists of the following components:

- Heating distributor
- Circulation pumps
- Pipeline network
- Heat exchangers
- Regulating valves + actuator
- Other fittings (shut-off valves, dirt traps etc.)

Together with the operating personnel, Sauter checks whether:

- The insulation is damaged or missing
- Actuators are defective
- The regulating valves are oscillating (continuous opening and closing)
- Cavitation noise is occurring in thermostats or other sections of the network

In order to save electrical energy, heat circulation pumps can be equipped with speed control, which is easy to carry out during modification work. Some pumps have this already. The operating personnel can set the optimum pump power by adjusting the pump characteristic at the control units. Because of the long service life of the pumps, a considerable amount of electrical energy can be saved, which results in the following rough estimate.

Pump output at full load	1200 W
Number of hours at full load	1700 hours
Number of hours at partial load	4300 hours
Average output with partial load	700 W
Electricity kilowatt hour rate	10 Cents/kWh
Unregulated power consumption	7200 kWh
Regulated power consumption	5050 kWh
Savings	215 EUR per year

Pumps with speed control also have the advantage that less cavitation noise occurs during partial load operation because the delivery head of the pumps is adapted to the required system output.

2.3.3 Heat utilisation

A large proportion of the heat is used for room heating and domestic hot water heating. The cost of room heating can be reduced by reducing the heat loss in the rooms. This can be done by:

- Insulating the outside of the building
- Using windows of a better quality
- Sealing the windows and doors
- Lowering the room temperature
- Correctly adapting the provision of heat to requirements
    - Using thermostats
    - Intelligent unitary control

Insulating the outside of the building and installing windows of a better quality can be carried out cost-effectively only during the construction of new buildings.
Lowering the room temperature should be tried out with extreme caution in hospitals. Discomfort and complaints about rooms that are too cold must be avoided. The room temperature is geared towards the patient's feeling of warmth and the doctor's specifications.
The use of intelligent unitary control, which makes it possible to block the supply of heat from the radiators if the window is open, for example, should be considered very carefully, as hospitals also have to be heated with the windows open to prevent the room from cooling down too much. Continuous ventilation with the heating on may be necessary in the wards for medical reasons.

2.4 Cooling

The hospital's cooling energy requirements are covered by a total of five refrigeration units, the main data of which is summarised in table 1. It can be assumed that the cooling requirement of the hospital will increase. The reasons for this are the addition of several operating theatres to the hospital and the associated start-up of additional ventilation systems.

Table 1: Technical data, cooling generation

	Absorption refrigeration units 1 and 2 (analogue)	**Compression refrigeration unit 1**	**Compression refrigeration unit 2**	**Compression refrigeration unit 3**
Refrigeration power Q_0	900 kW	Load operation: 290 kW (-1/-5 °C) Normal operation: 409 kW (4/10 °C)	250 kW	61 kW
Compressor power P_{el} or heating power	1350 kW	100 kW	52,2 kW	16 kW
Condenser power Q_K	2182 kW	≈ 500 kW	302.5 kW	77 kW
Evaporator design temperatures	6/12 °C	Load operation: -1/-5 °C Normal operation: 4/10 °C	6/12 °C	2/8 °C
Condenser design temperatures	27/34 °C	27/34 °C	27/34 °C	8/14 °C

In the winter months, the cost of cooling can be reduced by using free cooling. A heat exchanger with output of 100 kW has been provided for this purpose. Free cooling is started up when the outside temperature is 0 °C or below.

The compression refrigeration units allow the heat to be stored at the condenser side in the heating network instead of being removed via the cooling tower. As the temperature has to be higher in the case of waste heat utilisation (at least 70 °C) than it is when the condenser heat is removed via the cooling tower (30 °C), the performance of the refrigeration units can be expected to be deteriorate, as the condenser pressure also increases as the condenser temperature increases, which in turn increases the compressor output.
The refrigeration concept includes seven ice banks with a total refrigeration power of 4620 kW. Only refrigeration unit 1 is used to load the ice banks. Ice bank operation has the following advantages:

- Coverage of peak cooling requirement
- Peak electrical loads reduced at midday; this reduces the unit price of electrical energy
- Reduction in number of refrigeration unit switching cycles, therefore reducing wear
- Emergency reserves in the event of refrigeration unit failure

The control system between the refrigeration units and the ice bank has been optimised by Sauter in such a way as to make ice bank operation effective. This has significantly reduced the electricity peaks at midday, which saves a considerable amount of money with regard to the unit price. This optimisation also allows the refrigeration units to operate fault-free and efficiently. Frequent switching, which causes considerable wear and reduces the service life of the equipment, is avoided. Fault-free operation has been confirmed by the operator personnel.
The question to be asked with regard to the two different types of cooling generation (absorption refrigeration unit or compression refrigeration unit) is: "Which cooling generation method is the most cost-effective?". The absorption refrigeration units are operated using steam, whereas electrical energy is used for the compression units. Basically, one can say that the steam for the absorption units is low-cost, but the performance of the unit is extremely low, meaning that a relatively large amount of heat energy has to be used up to generate refrigeration energy. It is the other way around with compression units; in this case, the refrigeration yield is relatively high but the amount of electricity that is used is five times as expensive as steam.

Diagram 1

and Diagram 2

are used to evaluate the refrigeration generation procedure from the viewpoint of energy cost efficiency.

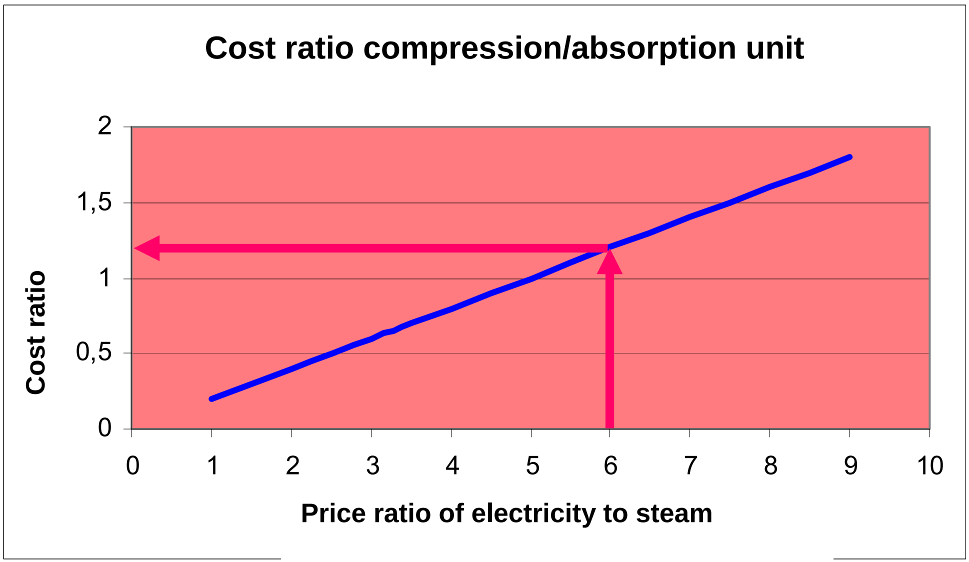

Diagram 1

Handling Diagram **1**

The dependence of the cost-effectiveness of refrigeration generation on energy prices (steam and electricity, which have the biggest influence on cost-effectiveness) can be determined using Diagram 1

The procedure is as follows:

1. **Calculation of price ratio of electricity to steam**
   The electricity price of the Westpfalzklinikum is approximately 12 cents per kilowatt hour, and the steam price for the absorbers is approximately 2 cents per kilowatt hour, which is a ratio of 6.
2. **Read off the cost ratio between compression refrigeration generation and absorption refrigeration generation** in diagram 1. The ratio is approximately 1.2, i.e. the specific cost per kilowatt hour of refrigeration is 1.2 times as expensive with compression refrigeration generation as with absorption refrigeration generation.

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For example, if the steam price increased to 2.8 cents per kWh and the electricity price to 12.2 cents per kWh, this would result in a price ratio of 4.35 and, therefore, a cost ratio of 0.85. At this price, generating refrigeration with the compression units would be cheaper. Working with price and cost ratios has the advantage that any price conditions can be examined. Average performance figures for the refrigeration units (performance figure of 3 for compression units and 0.6 for absorption units) were assumed when determining the dependence of the cost ratio on the price ratio. The dependence of the cost ratio on the performance figure ratio should be answered in Diagram 2

This is handled in the same way as Diagram 1

Calculation of absorption/compression unit performance number ratio

The performance number of the absorption units is approximately 0.6, and the performance number of the compression units is 3, which is a ratio of 0.2.

1. **Reviewing the cost ratio between compression refrigeration generation and absorption refrigeration generation** in diagram 2. At the current price ratio, the cost ratio is approximately 1.25, i.e. the specific cost per kilowatt hour of refrigeration is 1.25 times as expensive as with absorption refrigeration generation.

If the performance number of the compression units could be increased to 4, this would result in a performance number ratio of 0.15 and a cost ratio of 0.8 – in this case, the compression units are more cost effective.

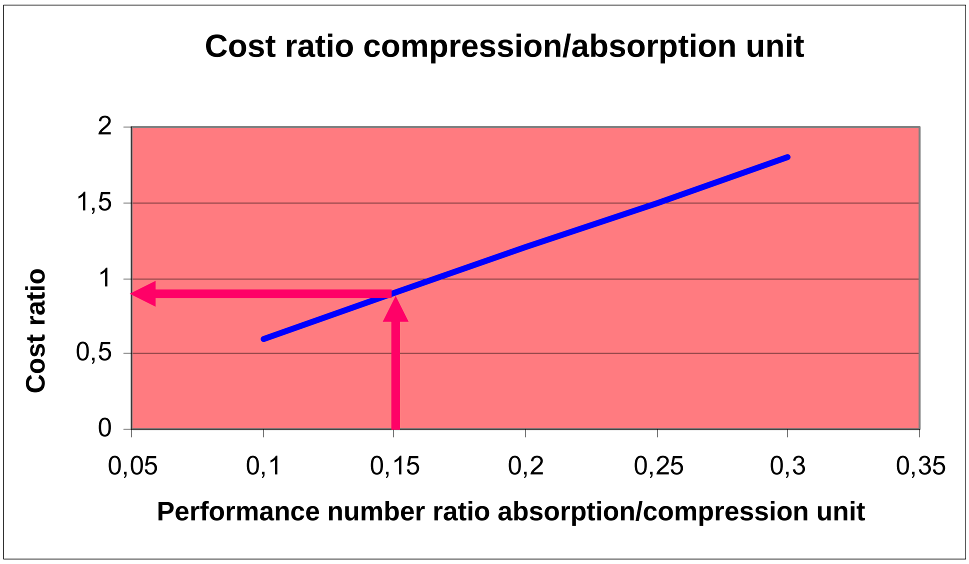

Diagram 2

When refrigeration is being generated with absorption units, it must also be taken into consideration that the operating costs of the cooling tower are higher than with compression units, particularly when operating the circulation pumps for the cooling tower water network and the fans in the cooling tower. The power prices for the provision of electricity and steam were not considered.
Currently there are no significant cost differences between the two refrigeration generation methods. The absorbers have the advantage that:

- They operate with little wear.
- The performance figure does not deteriorate during partial load operation

For this reason, preference should be given to using the absorber refrigeration units. Since the refrigeration generation costs make up a high proportion of the overall energy costs, the refrigeration units and the cooling towers should be equipped with heat and electricity measuring units. This is the only way to make definitive statements about the cost-effectiveness of refrigeration generation. The measuring results will help to optimise refrigeration generation, which promises to provide considerable cost savings. A system will be developed that contains the following:

- Arrangement of heat counters
- Measurement of water temperatures in the cold water network and the cooling tower network
- Historical recording of data
- Inclusion of refrigeration unit operating data
- Installation of operating hours counters

2.5 Lighting

Electrical energy for lighting can be saved by adapting the lighting to requirements:

- Movement sensors in corridors
- Dimmer switches
- Presence switches
- Time switching programmes
- Daylight-dependent dimming

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Sauter will check which of the named measures can be cost-effectively implemented for the Westpfalzklinikum.

It will also check where the lighting can be converted to electronic signal converters, which in the majority of cases is possible only during structural alterations. The following example calculation is for estimating the potential saving for a hospital corridor that would be possible to achieve by converting the lighting from conventional signal converters to electronic signal converters.

Number of lights	25
Output of lights	58 W
Power consumption of conventional signal converter	71 W
Power consumption of electronic signal converter	55 W
Daily usage time of lighting	15 hours/day
Electricity price	10 Cents/kWh
Saved kilowatt hours	2190 kWh/year
Cost saving	219 EUR per year

2.6 E-MAX

One way of cutting the unit cost of electrical energy is the E-MAX software from Sauter. The software can be used to reduce peak loads. Together with the operating personnel, Sauter will compile a list containing suitable consumers for peak load management, such as:

- Ventilation plants
- Electric heaters
- Refrigeration units

A 300 kW reduction in the connected load would reduce the power price by about 30,000 EUR/year, assuming an average power price of 100 EUR/kW* per year. The ice bank is particularly advantageous, as it makes it possible to switch off the refrigeration units during peak load times.

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3 Monitoring, energy management

Energy consumption can be conveniently balanced and visually evaluated through monitoring using the Sauter building management system. The data recordings of the building management system also make it possible to carry out detailed examinations such as:

- Control setting optimisations
- Fault detection and rectification
- Cost predictions
- Energy flow analyses