Energy Management and Energy Optimization in the Process Industry

SIEMENS

White paper

How does the fact that Siemens is becoming a "green company" benefit a plant operator in the process industry?

September 2011

"Our environmental portfolio makes us the global No. 1 in green technologies." (Peter Löscher, President and CEO of Siemens AG)

That is how Siemens asserts its claim of making a crucial contribution toward reducing the CO_2 emissions and the energy consumption of its customers.

What opportunities does this approach offer plant operators in the process industry?

Which Siemens products and services can make a contribution toward recording, monitoring and minimizing the energy consumption of process engineering plants?

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1 Introduction

In the light of rising energy costs, limited deposits of raw materials and global warming due to CO_2 emissions, the efficient use of energy is continually gaining importance.

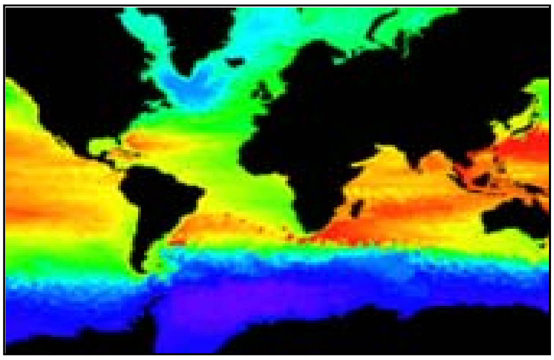

Fig. 1-1: Symbol of climate change – water temperatures of the world's oceans

The world's population is growing fast and, with it, the consumption of energy and resources. The consequence is a measurable change in climate. There is an immediate and urgent need for action in terms of reducing CO_2 output. In order to prevent devastating climatic damage (global warming of more than 2°C above pre-industrial levels), man-made emissions must be reduced by at least 25 to 40% by the year 2020 (relative to the reference year 1990)[3.].

Due to dwindling oil resources, the maximum rate of oil extraction using conventional means may already have been passed[4.], which means that further rises in energy prices can only be expected.

A further motive for saving energy arises from recent events in Japan: Energy saved means less energy generated by nuclear power, i.e. all measures for improving energy efficiency also make a contribution toward the desired "energy turnaround" in the direction of a regenerative energy economy.

1.1 A Change of Attitude

This development has led to a general change of attitude that is reflected as much in everyday life as in industrial production and which characterizes the approach for technical innovations. To take a few examples:

- Cars: Whereas car advertisements previously highlighted engine power [PS] and maximum speed [km/h], key data such as fuel consumption [l/100 km] and CO_2 emissions [kg CO_2/100 km] now play a significant role. A car in 1970 (VW Beetle) had a consumption of 12 l/100 km with a weight of just 750 kg. Today a mid-range car requires just half this fuel, despite being double the weight.

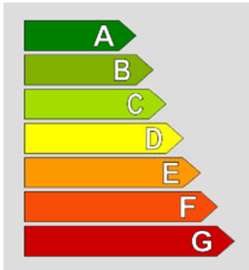

Fig. 1-2: Energy-efficiency classes according to the EU energy label for electrical appliances

- Domestic appliances are categorized today in energy efficiency classes A to G[6.]: A modern washing machine uses 35% less electricity and 46% less water than one produced in 1993. A low-energy light bulb consumes 80% less electricity than an incandescent bulb of comparable brightness, while an LED lamp uses up to 89% less.

The term Sustainability, best known for its connotations in forestry, is now on everyone's lips. Sustainability in forestry refers to the method of management of a forest, in which no more wood is extracted than can be grown again, so that the forest is never completely cleared, but is continuously regenerated. For Siemens, sustainability means acting in a responsible manner with respect to future generations – at an economical, ecological and social level[7.].

"Our environmental portfolio makes us the global No. 1 in green technologies." (Peter Löscher, President and CEO of Siemens AG)

That is how Siemens asserts its claim of making a crucial contribution toward reducing the CO_2 emissions and the energy consumption of its customers.

The products and systems of the Siemens environmental portfolio installed for Siemens customers saved the environment about 270 million metric tons of CO_2 in fiscal year 2010. By 2011 Siemens wants to raise these savings to 300 million metric ton per year.

What opportunities does this approach offer plant operators in the process industry?

After raw materials, energy is the second largest cost factor in the process industry, even ahead of labor costs. In future this cost will be pushed up by increasing costs, dependent on energy consumption, for CO_2 emission certificates. As a considerable proportion of the CO_2 emission quota for the period up to 2050 has already been consumed since the turn of the millennium, the financial incentives to cut CO_2 emissions will have to be strengthened [1.].

Improvement of energy efficiency therefore has a two-fold benefit: it benefits not only the environment and the climate, but also the profitability and competitiveness of companies. Economic and ecological interests are in harmony here and the potential is great [2.] :

- Energy savings of 15% can be achieved in industrial plants by means of intelligent process automation.
- 70% of the electrical energy demand in industrial plants is required for drives.

Siemens itself it leading the way in this respect with its own production plants [7.].

The improvement of its own CO_2 efficiency by 20 percent in fiscal year 2011, relative to emissions from the use of energy, is a key target for Siemens. An improvement of 20% in the efficient use of water is also being targeted at its own production sites.

1.2 Definitions

Energy efficiency

(Definition according to DIN EN 16001 or ISO 50001)

The ratio between achieved performance or the profits from services, goods or energy, and the energy used to achieve this.

Energy management

(as defined in DIN 4602)

Energy management is the predictive, organized and systematic coordination of the procurement, conversion, distribution and use of energy to cover requirements while taking account of ecological and economic aims. The term thus describes actions for the purpose of efficient energy handling.

Energy management system

The term energy management system encompasses the organizational and information structures, including the required technical tools (e.g. hardware and software) needed to implement energy management.

In the stricter sense, it is a technical system for gathering, analyzing, documenting, and visualizing energy data, as well as for regulating and monitoring energy consumption in plants and buildings.

In August 2009 the definitive final version of the European Standard DIN EN 16001, Energy Management Systems, came into force. The application of DIN EN 16001 should support the establishment of a continuous improvement process in energy efficiency. It describes fundamental components of the energy management system (EMS) in the company such as the definition of an energy policy, the recording and documentation of the flow of energy, the evaluation of energy saving potential and the future-oriented planning of the associated activities.

Some aspects of DIN EN 16001:

- Measuring, monitoring and recording of essential energy consumption.
- Planning energy consumption, setting and monitoring targets
- Introducing, documenting and implementing energy efficiency targets
- Identifying areas with extensive energy consumption or with extensive changes
- Considering energy aspects in operational targets
- Linking energy consumption to data on production figures
- Definition of possible measures for energy saving
- Regular benchmarking of the indicators of energy efficiency

1.3 Raising Efficiency as a Continuous Process of Improvement

Energy management in a production plant is not primarily a product, but a permanent process of improvement (operating sequence), comparable with quality management.

When improving energy efficiency and conservation of resources, Siemens implements a holistic consideration of the plant as well as of the product life cycles in the context of energy management (EN 16001). In this respect, the intelligent combination of end-to-end processes, targeted services and an integrated technology portfolio offers great potential within industry and infrastructure.

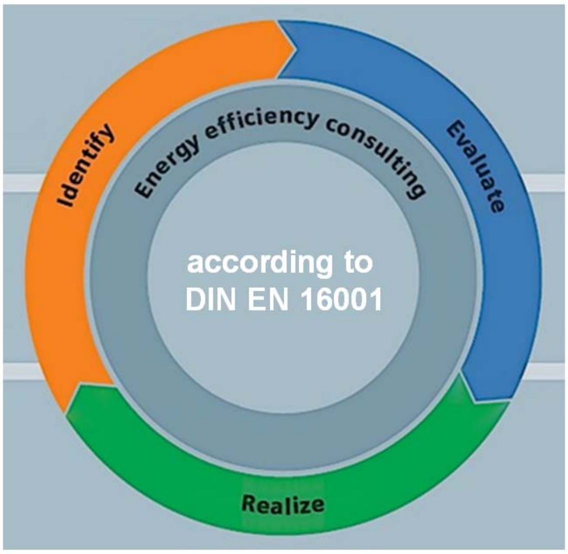

Fig. 1-3: Energy management as a permanent process of improvement in the company

The concept of Siemens Industry [2.] is based on the three phases of "identification", "evaluation" and "implementation". The "identification" phase is a matter of using appropriate automation hardware and software (see Section 4) to detect the energy flows in the plant and to enable identification of the "energy guzzlers" within the plant. This involves targeted and consistent recording of energy data as process parameters, starting with the sensors and actuators, then proceeding through the control level to the management control level. In the "evaluation" phase the potential savings are calculated. The third phase of "implementation" involves leveraging the agreed potential savings by means of firm actions. Special note should be taken of the drive technology (see Sections 4.4.3 and 4.4.4) which, according to [2.] , accounts for around two thirds of industrial energy consumption.

Continuous energy management results in a lasting increase in productivity – through energy saving, continuous load management, the compensation for peaks in energy demand by means of load shifting and the planning of the energy demand. This is because productivity potential can no longer be leveraged just by means of more efficient isolated solutions. There is a much greater necessity for the seamless horizontal and vertical integration of information, communication, and automation technologies into the operating processes. Everything from a single source: to supplement its innovative products, systems and solutions, Siemens offers its customers in industry and infrastructure tailor-made services for in-plant energy management (see Section 5).

2 Anchoring Energy Efficiency in Statutory Framework Conditions

2.1 Climate Conference and Energy Concept

In December 2010 the representatives of almost 200 states met for the UN Climate Conference in Cancun, Mexico. The agreed overall objective was to prevent global warming from raising the temperature by 2 degrees above pre-industrial levels by 2020.

The signatories of the Kyoto Protocol will reduce CO_2 emissions by between 25% and 40% of the 1990 levels. In addition, they were able to agree to implement considerable further reductions in the emissions of greenhouse gases by the year 2050. There will be an option to reduce the overall target of 2 degrees warming to just 1.5 degrees. These agreements, however, are not binding. At the next climate conference in Durban, South Africa at the end of 2011 a new climate protection agreement, or at least the binding reduction of emissions is to be negotiated.

Extensive measures were defined in the energy concept of the German Federal Government in September 2010 for achieving the climate protection targets by the year 2050. These include the use of renewable energy sources and cover the sectors of intelligent networks, buildings and traffic. The increase in energy efficiency in industry is identified here as a key topic. Energy efficiency over the entire life cycle of a product or system should be an important criterion when awarding public-sector contracts. According to scientific studies, the energy saving potential within German industry amounts to 10 billion Euros per year. In order to identify and leverage this potential, companies should be obliged to introduce energy management systems compliant with international standards (EN 16001, ISO 50001). In future, tax concessions will be more closely linked to corporate energy savings, which it will be possible to verify with the aid of the data recorded in the energy management system. For example, the compensation scheme for large energy-consuming enterprises contained in the Renewable Energy Act (EEG) and aimed at reducing energy costs is only guaranteed if it can be proved that the energy consumption and the potential for reducing the energy consumption have been ascertained and evaluated. The Draft Act of the Federal Government dated 6.6.2011 contains a progressive restriction of the EEG allocation for favored companies. For the consumption of 1 – 10 gigawatt hours, the concession is reduced to 10% of the allocation. For the consumption of between 10 and 100 gigawatt hours, only 1% of the allocation is due. For consumption of over 100 gigawatt hours, the EEG allocation is limited to 0.05ct/kWh. The EEG allocation has risen continuously (2008: 1.2 ct/kWh / 2009: 1.2 ct/kWh / 2010: 2.047 ct/kWh / 2011: 3.53 ct/kWh). The forecast of the German transmission network operators for the bandwidth of values to be expected for the EEG allocation in 2012 is between 3.4 and 4.4 ct/kWh.

In February 2011, the Federal German Government passed a draft act for renewal of the Greenhouse Gas Emissions Trading Act (TEHG). Among other things, the obligation to trade emissions will be extended after the 2013 trading period to general plants, with a total rated thermal input of more than 20 MW, that are used for the combustion of fuels. This mainly affects the process furnaces that were not previously recorded. From 2013, the number of certificates issues will be reduced continuously by 1.74% per year. Accordingly, the total amount of emissions will fall and thus make a considerable contribution to reducing the emission of greenhouse gases in Europe.

2.2 Transparency of Consumption and Emissions, CO_2 Footprint

In principle, it is sensible for a company to have the most accurate knowledge possible about the resources used and the energy consumed. Within the scope of current discussions about climate change, particular importance is attached to recording the emissions produced. In order to be able to influence the situation, transparency about the creation of the emissions is required. The "climate-friendliness" of products is becoming an increasingly important factor that can also have a decisive influence on the purchasing decisions of customers. For many products there are particular key aspects when considering emissions. For some products it is more a matter of the manufacture, while for others it is their energy consumption in use. Yet emissions are created throughout the entire life of a product: from the extraction of raw materials, through the production and trade chain to the final disposal or recycling. The manufacturer has a host of opportunities for influencing this cycle. However, to be able to do so, it is necessary to assign the materials used and the quantities of energy required according to the originator. This information is then forwarded to the manufacturing company by the suppliers of the raw materials or semi-finished products.

For the environmentally conscious end-user today there are already various labels for classifying the environmental impact of products, e.g. energy efficiency classes of domestic appliances or CO_2 emission figures for cars or various environmental certificates. The labels issued today, however, are subject to variance in terms of the emissions and life-cycle phases under consideration. A standardized classification system in future could be an even greater help when making purchasing decisions, as it would start to move the market in the direction of more sustainable products. Companies that offer sustainable products and solutions would then have a competitive edge. For the consumer, the attractions of these products would be two-fold, as they both protect the environment and are better value due to their sparing use of resources.

One method of presenting an ecological balance sheet is the recording of the "product carbon footprint".

"The product carbon footprint denotes the quantity of greenhouse gas emissions over the entire product life cycle in a defined application and relative to a defined unit of use." (Definition from the draft of ISO 14067 "Carbon Footprint of Products".)

This involves converting the volumes of gaseous substances that increase the strain on the climate and that are created over the entire life cycle and value-added chain of a product, into CO_2 equivalents and recording them. Using "emission factors", the consumption of electrical energy, for example, can be converted into CO_2 equivalents. This takes into account all six greenhouse gases named in the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), sulfur hexafluoride (SF_6), nitrous oxide (N_2O), and chlorofluorocarbons (HFCs and PFCs). Although these greenhouse gases have total emission volumes significantly lower than those of CO_2, they are characterized by the fact that their "global warming potential" (GWP) is higher by several orders of magnitude than that of CO_2. The GWP ranges from 25 for methane, and 298 for nitrous oxide, to the order of between 1000 and 14,800 for the fluorinated gases. At the top of the list is sulfur hexafluoride (SF_6) with a GWP of 23,900 which means that one metric ton of SF_6 has the same greenhouse gas effect as 23,900 metric tons of CO_2.

CO2 equivalents	Source	GWP
Carbon dioxide (CO2)	Combustion of fossil fuels and biomass	1
Methane (CH_4)	Rice farming, cattle farming, sewage treatment, landfill waste, mine gas, natural gas and oil production	25
Nitrous oxide (NO_2) (laughing gas)	Nitrogen fertilizers, combustion of biomass	298
Chlorofluorocarbons	fuel gases, coolant, filling gas for plastic foams	124 - 14,800
Sulfur hexafluoride (SF_6)	Insulating gas in high-voltage switchgear	23,900

Table 1-1: Greenhouse gases and CO_2 equivalents (Source: Wikipedia)

So far, however, the product carbon footprint has been of only limited informational value. To make the data more transparent and comparable, standardized rules must apply to the recording of data. In addition, the emission of greenhouse gases is only one relevant indicator of a product's environmental compatibility. This approach may be extended to other resources in future. Raw materials in short supply, water consumption, or the quantity and toxicity of waste during manufacture could likewise be considered, in order to define a comprehensive parameter for the environmental impact and sustainability of a product. Furthermore, even social and ethical factors, such as the use of child labor, could be incorporated.

3 Overall Picture of the Energy Flow Chain

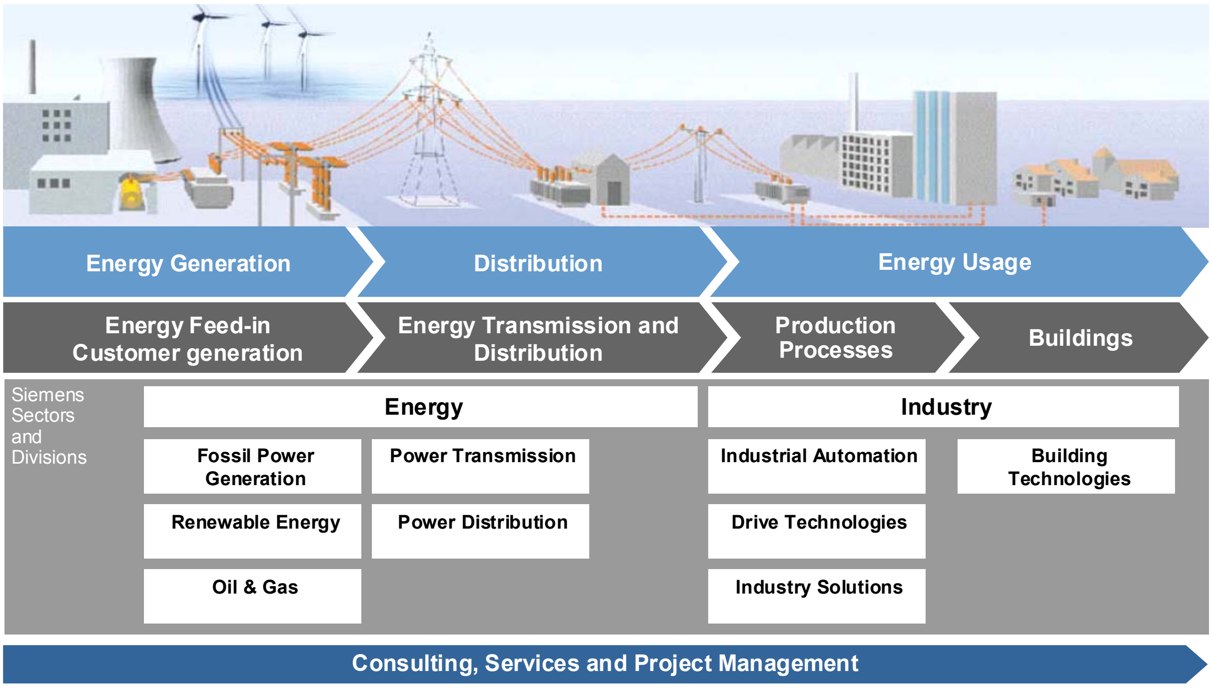

Fig. 3-1: Siemens products and services along the entire energy flow chain

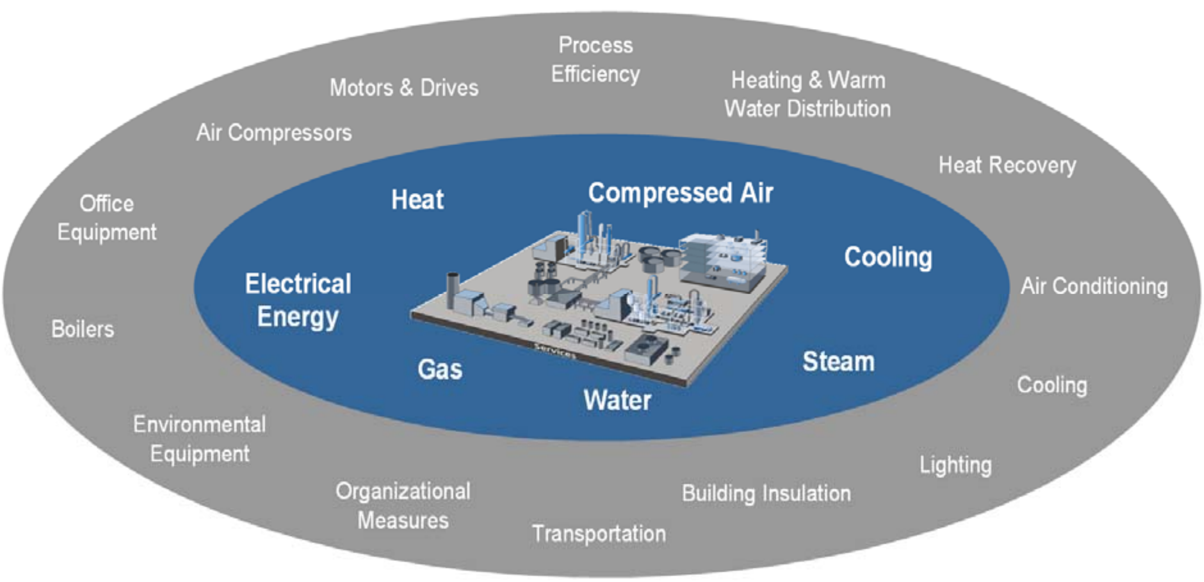

Fig. 3-2: Forms of energy and energy management topics in a process engineering production plant

Siemens is the only company in the world to offer its customers efficient products and solutions produced with its own expertise in its own production plants along the entire energy conversion chain – from oil and gas extraction, through generation to the transmission and distribution of electrical energy.

The activities of the various divisions of the Siemens Energy and Industry Sectors are arranged along the entire energy flow chain in the diagram above.

3.1 Power Generation

The Siemens Energy Sector [9.] supplies complete solutions for

- Industrial power plants and combined heat and power plants
- Gas turbines and steam turbines
- Generators and compressors

In the field of renewable energies, solutions are offered for:

- Small hydroelectric power plants
- Wind energy plants
- Solar thermal and photovoltaic plants and inverters
- Steam turbo sets for geothermal power plants

What is more, the Industry Sector also supplies automation solutions for plants that produce biofuels (e.g. biogas, bioethanol).

3.2 Power Distribution

In the field of power transmission, Siemens offers:

- High-voltage switchgear
- High-voltage products
- High-voltage DC transmission systems (HVDC)
- Flexible AC transmission systems (FACTS)
- Network access solutions
- Gas-insulated transmission lines
- Transformers

In the field of power distribution, Siemens offers:

- Medium-voltage switchgear and equipment
- Onshore power supplies
- Outdoor vacuum circuit breakers etc.
- Infrastructure for electromobility

3.3 Energy Consumption

Due to conversion losses and consumption by the energy sector itself, only 65% of the primary energy consumed in Germany actually reaches the end-user.

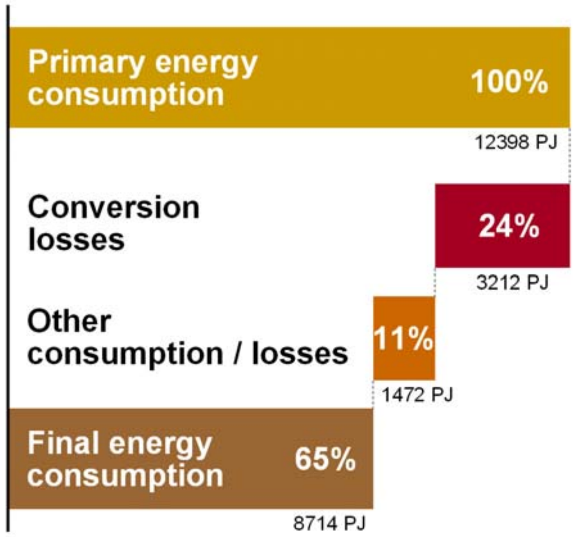

Fig. 3-3: Energy flow in the Federal Republic of Germany in 2009 in petajoules [PJ], 29.308 PJ = 1 million metric tons of coal equivalents. Source: Arbeitsgemeinschaft Energiebilanzen (German Energy Balance Working Group) 07/2010

End-user energy consumption is shared in roughly equal proportions by transport, households and industry. In the context of process automation, of course, the focus is on energy consumption within industry.

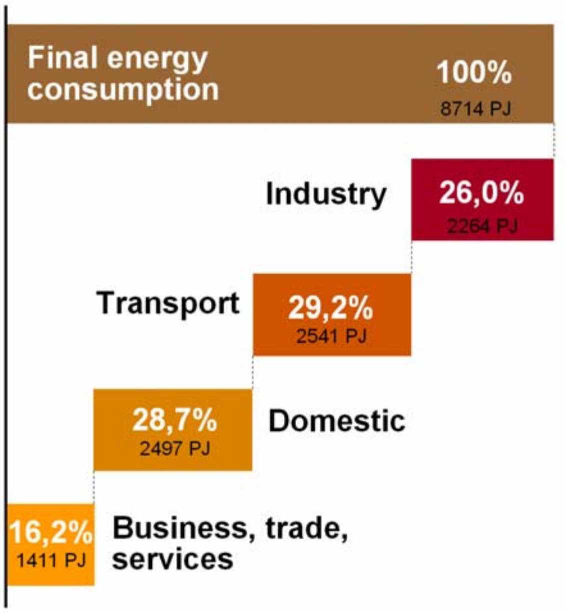

Fig. 3-4: Distribution of energy consumption in the Federal Republic of Germany, 2009. Source: Arbeitsgemeinschaft Energiebilanzen (German Energy Balance Working Group) 07/2010

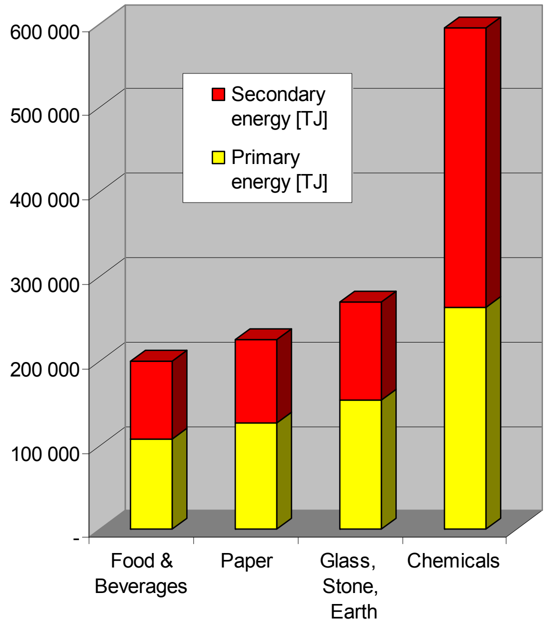

Fig 3-5: Energy consumption of various sectors of the process industry in Germany

3.3.1 Consumption in Production Processes

The host of different products and methods that are used in production and production processes, that in some cases are extremely sensitive, necessitate a reliable and efficient supply of energy and raw materials. In a process engineering plant as many as seven different energy sources play a vital role: Fig. 3-2.

The recording, monitoring and minimization of the energy consumption in production processes of the process industry as well as the optimized procurement of energy is the focus of this White Paper and will be described in greater detail in Sections 4 and 5.

From the comparison of the different sectors of the process industry in Fig. 3-5 it is clear that the chemical industry has the highest consumption and therefore the greatest potential for savings.

How will this energy demand be covered? Fig.3-6 shows that electrical energy and gas play a significant role here.

For the sake of completeness – because it is of importance in various process industries – energy consumption in buildings will be discussed briefly here.

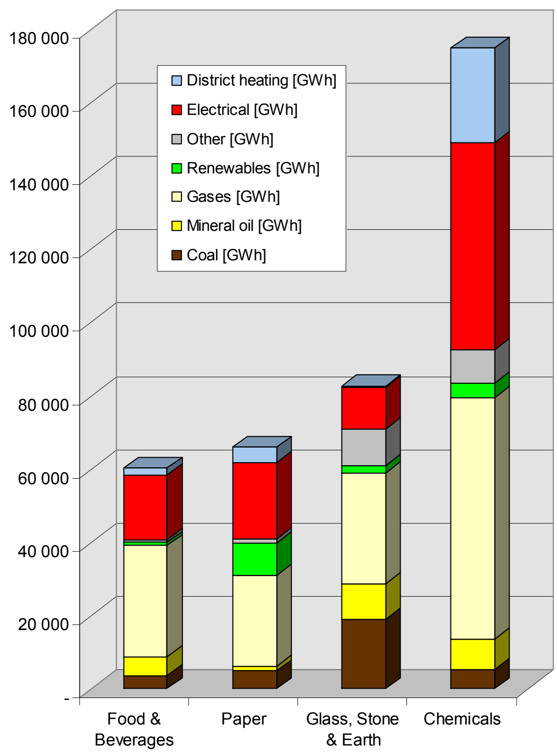

Fig 3-6: Energy mix in the process industry

3.3.2 Consumption in Buildings

The Siemens Building Technologies Division offers a complete technical infrastructure portfolio for comfort, energy efficiency and security in buildings and public infrastructure. Specifically in the field of building automation, energy efficiency plays an important role: [10.]. 40% of energy consumption worldwide is accounted for by buildings and with the aid of building automation, energy savings of up to 30% can be achieved.

Innovative solutions, systems, products and services are aiming at an optimum balance between building performance, comfort and sustainability in order to maximize efficiency, in accordance with European Standard EN 15232, Class A.

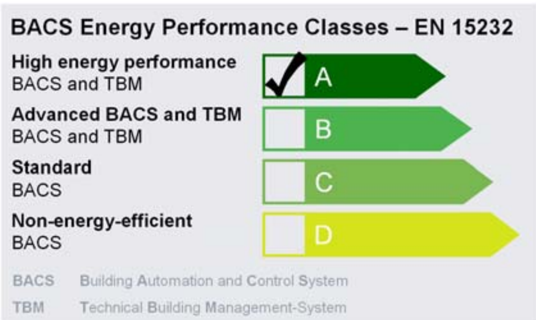

Fig 3-7: Energy classification of buildings according to EN 15232

	Thermal energy				Electrical energy			
Class	D	C	B	A	D	C	B	A
Offices	1,51	1	0,80	0,70	1,10	1	0,93	0,87
Lecture hall	1,24	1	0,75	0,50	1,06	1	0,94	0,89
Education	1,20	1	0,88	0,80	1,07	1	0,93	0,86
Hospitals	1,31	1	0,91	0,86	1,05	1	0,98	0,96

Fig. 3-8: Energy consumption of different classes of building, with reference to the standard (Class C)

Examples of products from Siemens Building Technologies that contribute to energy efficiency:

- Symaro sensors for determining air quality (e.g. CO_2 concentration in the ambient air) are the basis for demand-driven ventilation that ensures a constant air quality as the number of occupants or the use of a room changes and therefore enables energy savings of between 20 and 70% to be made.
- Variable-speed drives such as the SED2 for fans and pumps save up to 50% of the drive energy.
- Open Air damper actuators permit precise positioning with minimum use of energy, thanks to a drift-free measurement with automatic zero-point correction.
- Energy-saving contracting: The formula for successful energy-saving contracting at Siemens is to finance essential investments in modernization by means of the savings in energy and operating costs. The Siemens guarantee ensures the economic efficiency of all measures, the maximization of energy efficiency, greater convenience and productivity. These measures reduce the environmental impact on a lasting basis.

Fig. 3-9: Siemens energy-saving contracting

4 Automation Components for Energy Efficiency in the Production Process

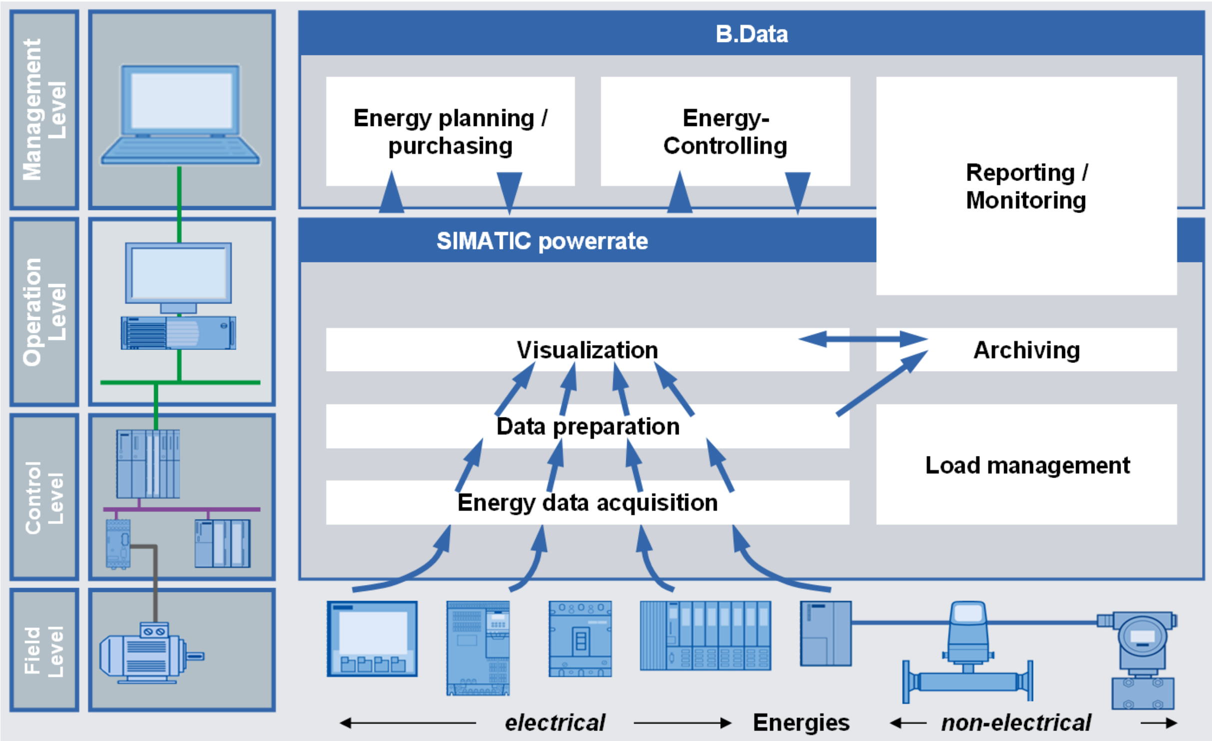

Fig. 4-1: Standard components for energy efficiency and energy management

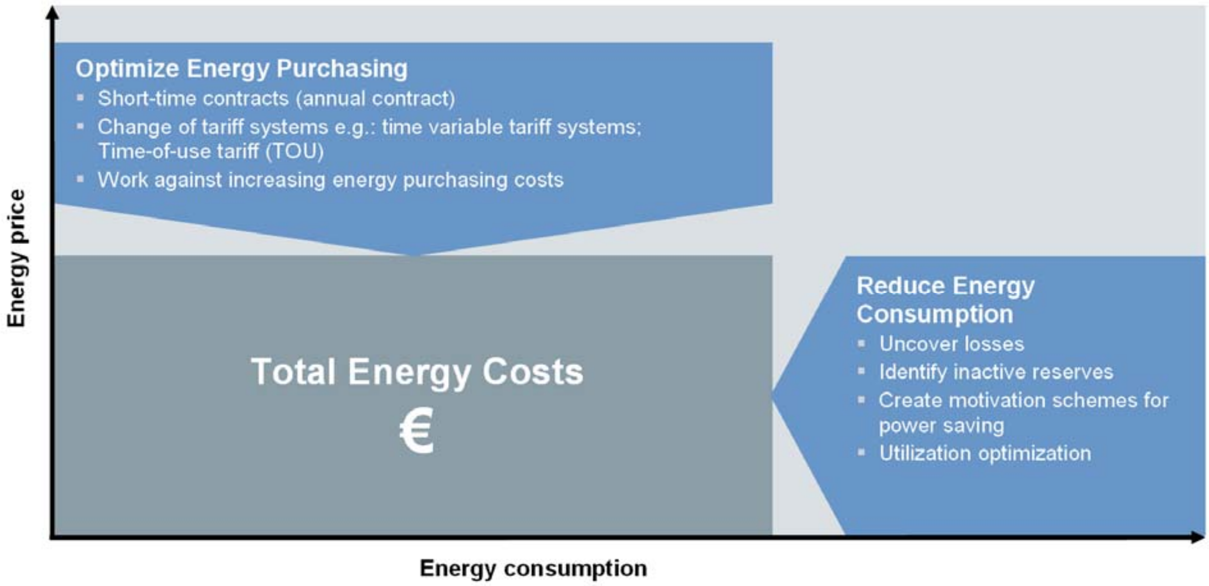

Fig. 4-2: Minimization of energy costs using two essential levers: the energy quantity and the contractual framework conditions

Which products of the Siemens Industry Sector can plant operators in the process industry use in order to optimize the energy efficiency of their plants? [8.]

This question is considered across all levels of the automation pyramid. Totally Integrated Automation – the integrated basis for implementing customer-specific automation solutions – provides maximum transparency at all levels, thanks to its reduced interfacing overhead, from the field level, through the plant management level to the corporate management level. With Totally Integrated Power (TIP), Siemens offers coordinated products and systems and therefore integrated solutions for energy distribution in industry – from the medium-voltage network to the wall outlet.

At the field level, it is a matter on the one hand of recording energy consumption, taking into account both electrical and non-electrical forms of energy, and on the other hand the minimization of energy consumption through the use of energy-efficient devices such as motors, frequency converters, soft starters, switching and protection devices, as well as power supplies.

At the control level it not only involves the collection, aggregation and preparation of the energy consumption data from the field level, but also the minimization of the energy consumption by optimizing the process management with the aid of advanced process control and asset management functions.

At the operator control and monitoring level it involves, on the one hand, visualizing the consumption data with characteristic values, graphs and other graphical presentations and, on the other hand, the archiving of energy data and the generation of reports (by unit, batch, plant section etc.).

Finally, at the management level it is a case of planning and procuring the energy, and of controlling and monitoring the energy, whereby a clever combination of load management and time- or load-dependent tariff systems enables the procurement costs to be minimized: Fig. 4-2.

4.1 Management Level

The "Management Level" refers to the level shown in Fig. 4-1 above the process control system which is also often called the MES level.

4.1.1 B.Data: Energy Management System at Corporate Level

B.Data [11.] permits optimized and cost-effective energy management in the areas of controlling, planning and energy purchasing. B.Data creates transparency by means of seamless balancing of energy and material accounts, thus enabling energy costs to be charged to the parties responsible and creating a connection to the accounting system. The accumulated characteristic values allow substantiated statements to be made regarding the increase in efficiency.

- Energy controlling: B.Data offers seamless data acquisition and preparation. This ensures a transparent energy balance and simplifies compliance with statutory regulations, such as monitoring and reporting greenhouse gas emissions. The specific determination of key performance indicators (KPI) and incorporation of production data allows substantiated statements to be made regarding the increase in efficiency.
- Energy cost determination: The flexible pricing and modeling of energy and material flows in B.Data enables energy costs to be determined and charged to cost units on a cost-by-cause basis, and ensures the transfer of energy quantities/costs to the ERP system (such as SAP R/3 CO).
- Energy planning: B.Data enables an exact prognosis of energy needs and load curve. This optimizes the budget planning and allows current production to be quickly adapted at any time, with the highest degree of decision-making certainty.
- Energy purchasing: B.Data provides all relevant information at all times about the required amount of energy in the course of the day and year: the basis for optimum energy purchasing terms.

4.1.2 Simatic IT: Energy Management

Within the scope of the MES functionalities of Simatic IT, energy data can also be processed, for example, for the job-oriented balancing of energy consumptions.

4.2 Operation and Monitoring Level

4.2.1 SIMATIC powerrate for PCS 7

SIMATIC powerrate [12.] is available as an add-on for SIMATIC WinCC and SIMATIC PCS 7 and is used for standardization, visualization and archiving of energy and output averages with time stamps. The plant consumption data is gathered via the field bus and compressed and buffered in the SIMATIC S7-CPU. The transparency of the energy consumptions is a basic prerequisite for an optimization. Energy management is thus anchored alongside the operator station and the maintenance station as the third pillar of the process control system.

The software package contains PCS 7 function blocks (→ control level) for the following tasks:

- Recording and standardizing of energy data of any media by means of pulses, work units or performance data.
- Calculation of the performance averages and work values relative to freely definable periods of time.
- Determination of a projected work/performance value relative to the end of the period (linear projection of the work for the respective period).
- Synchronization with utility pulse.
- Buffering of the average values in the cyclic buffer on the SIMATIC S7-CPU.
- Integration of the Sentron PAC 3200 / PAC 4200 multi-function measuring devices (see Section 4.4.1.1)

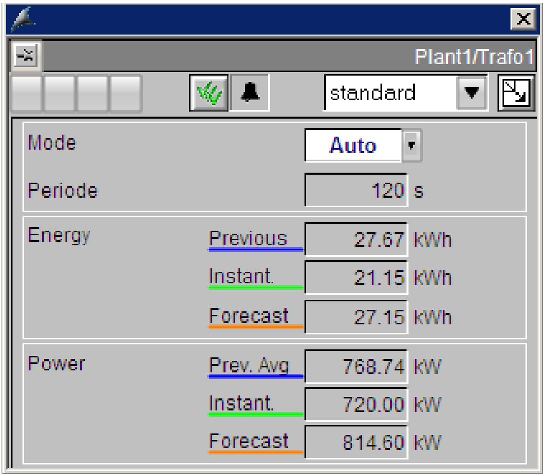

Fig. 4-3: PCS 7 faceplate of SIMATIC powerrate for one power consumer

For the purpose of visualization, special faceplates are prepared and otherwise all standard means of the process control system are used for threshold monitoring, trend presentation, archiving etc.

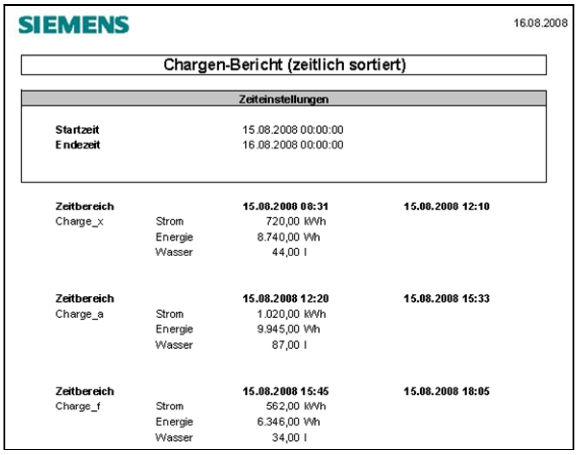

Fig. 4-4: Log for the energy consumption of batches

In addition, functions are available for the configurable generation of energy reports in Microsoft Excel.

- Standard forms for the assignment of measuring points to the associated cost centers and comparison
- Configurable tariffs (high, low and public holiday tariffs)
- Cost center reports with consumption values and costs (as tables and bar charts)

The load management in SIMATIC powerrate helps to prevent limits being overshot and aids adherence to the contract conditions with the utility company; it also permits, where appropriate, more favorable purchasing conditions by reducing the peak load.

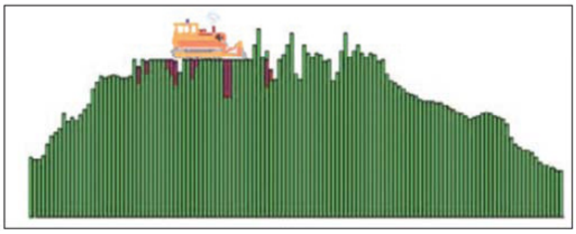

Fig. 4-5: Recognize and shift load peaks and fulfill power consumption constraints

For this purpose, functions can be configured for automatically switching consumers on/off if there is a risk of exceeding a limit. There is a priority list for the on/off switching, alternate switching for the same priority and configurable maximum/minimum on/off times. Conversely, the temporary connection of generators (e.g. emergency diesel) is conceivable in order to avoid foreseeable peak loads, provided the generators can be started and synchronized quickly enough.

In process engineering continuous process plants, only auxiliary units with buffering capability come into consideration for automatic shutdown, e.g. cooling equipment with a coolant reservoir. In batch processes an intervention via the batch planning is conceivable, for example to prevent several batches with particularly energy-intensive heating procedures from being started simultaneously.

4.3 Control Level

4.3.1 Advanced Process Control

APC (Advanced Process Control) methods are a tool of vital importance for improving plant efficiency while at the same time safeguarding product quality and operability. Depending on the requirement situation, APC functions can be used for reducing energy consumption at constant throughput, or for raising throughput without a corresponding rise in energy consumption.

APC solutions can be realized much more cost effectively due to a DCS embedded implementation with standard function blocks and predefined CFC templates as offered by Siemens in the PCS 7 Advanced Process Library [13.].

Now APC solutions are available for many standard applications.

Unnecessary manipulated variable movements can be avoided by improved controller tuning (e.g. with the aid of a PID tuning tool). Oscillations of actuators (e.g. valves) consume energy (e.g. compressed air) and cause wear.

A model based predictive controller (MPC) reduces the variances of manipulated and controlled variables by holistic consideration of the whole plant unit (multivariable control) and forward-looking ("predictive") planning of manipulated variable moves.

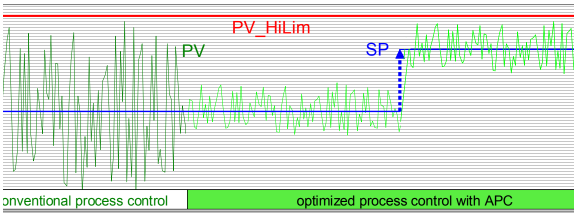

Fig. 4-6: Optimized process operation with Advanced Process Control (APC)

The reduced variance (standard deviation) allows moving the setpoints closer to critical constraints without the risk of frequently violating the constraints. By pushing the system to its physical limits (capacity, safety and product quality), the throughput can be increased considerably, for instance, or the energy consumption reduced significantly.

By means of an integrated economic online optimization of the steady state operating point inside the model predictive controller, the energy consumption can be explicitly considered and minimized in the performance index (target function), while at the same time fulfilling the constraints with regard to production.

Considering a distillation column as an example, the energy consumption can be minimized by zone control of product quality (head and bottom temperature) with simultaneous minimization of the manipulated variable hot steam flow - resulting in an automatic optimal reduction of reflux ratio.

4.3.2 Asset Management of Mechanical Components

Various types of wear on mechanical plant components (assets) can impair their operation efficiency over time and thereby raise energy consumption. Examples:

- Fouling on heat exchangers reduces the heat transfer coefficient and thereby increases the consumption of the service medium (e.g. hot steam, coolant).
- Fissure wear or cavitation damage reduces the delivery head of centrifugal pumps and raises the energy consumption of the pump drive.
- Caking on valve bodies or clogging of filters increases the flow resistance and raises the energy consumption of the associated pumps.

By online condition and performance monitoring of mechanical assets, such phenomena can be recognized at an early stage and considered in the maintenance planning. This not only helps to improve the availability of the plant, but also to avoid "backdoor" energy wastage.

By visualizing the current operating point in the set of characteristic curves of the components and by means of a statistical evaluation of the operating period in various load ranges, the user can recognize whether the component is being used efficiently while in service.

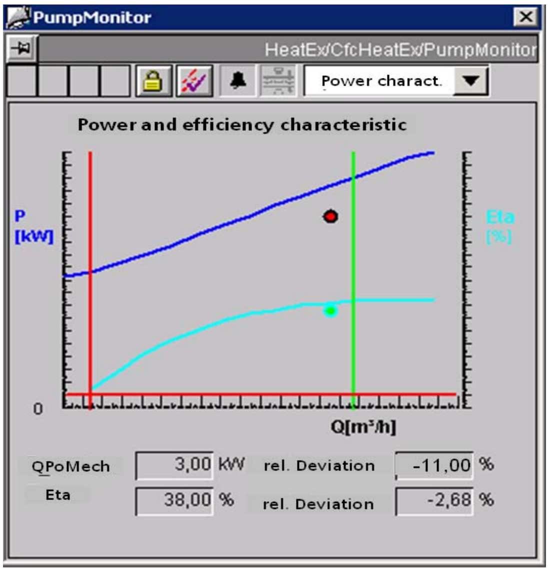

Fig. 4-7: Faceplate of the PCS 7 PumpMon function block with characteristics curves for mechanical shaft power and hydraulic efficiency dependent on flow

For the following mechanical assets, Siemens provides dedicated monitoring function blocks (either as an add-on product or prototype for pilot tests) in PCS 7 [14.]:

- Centrifugal pumps: PumpMon
- Heat exchangers: HeatXchMon
- Continuous control valves: ValveMon
- Filters and other flow resistors: PressDropMon
- Turbo-compressors: CompMon

The monitoring of mechanical components is integrated into the SIMATIC PCS 7 maintenance station in which the "electrical" components of the automation system (process control system, sensors and actuators) are monitored as well.

4.4 Field Level

4.4.1 Measuring Devices for Electrical Energy Flows

4.4.1.1 SENTRON PAC Multifunction Measuring Instruments and E-Counters

The multi-function measuring instruments SENTRON PAC3100 / 3200 / 4200 and SENTRON PAC1500 E-counters [15.] record the power data of electrical feeders and individual consumers precisely and reliably. They also supply important measured values for assessing the quality of the power supply. For further processing of the measured data, the devices can easily be integrated into higher-level automation and energy management systems such as SIMATIC PCS 7 and SIMATIC powerrate thanks to their versatile communication options.

4.4.1.2 Power Electronics for Motors as an Intelligent Field Device

In many cases the electrical active power that is fed in is already recorded in the power electronics (converter, soft starter, motor management system, see Section 17) belonging to an electrical drive. If these devices are integrated as intelligent field devices into a process control system, the ascertained energy consumption data can be directly evaluated within the context of the energy management system.

4.4.2 Measuring Devices for Non-Electrical Energy Flows

4.4.2.1 Fossil Energy Sources

To measure the flow quantities of fossil fuel energy sources, such as natural gas and oil, standard flow meters can be used, e.g. from the SITRANS F class of devices: [25.]. In order to convert to energy quantities, the higher or lower heating value must be known. The higher heating value is a measure of thermal energy stored within a material, relative to the quantity of the material. The lower heating value is the maximum usable quantity of heat obtainable from combustion, where the water vapor contained in the exhaust gas does not condense, relative to the quantity of the combustion material used.

4.4.2.2 Heating Steam

Heating steam is typically produced at a central location and distributed to individual consumers through a plant-wide network. The heating steam is taken from a steam supply line at a defined pressure (e.g. "20 bar line"). As it refers to saturated steam in the non-critical range, the assigned temperature can be calculated by means of the dew point line. The (volumetric) flow of the heating steam is normally measured (for example with SITRANS F devices) so that it can be regulated. From the pressure and temperature, the density and thus the steam mass flow can be calculated. The energy flow in [kJ/s], i.e. in [kW], is calculated from the specific enthalpy [kJ/kg] and mass flow [kg/s].

4.4.3 Power Electronics for Motors

4.4.3.1 SINAMICS Frequency Converters and Inverters

For pump systems with frequently fluctuating or part-load operation in particular, it is worth using a speed regulation based on need with the aid of frequency converters or inverters, instead of a mechanical flow control using throttle valves.

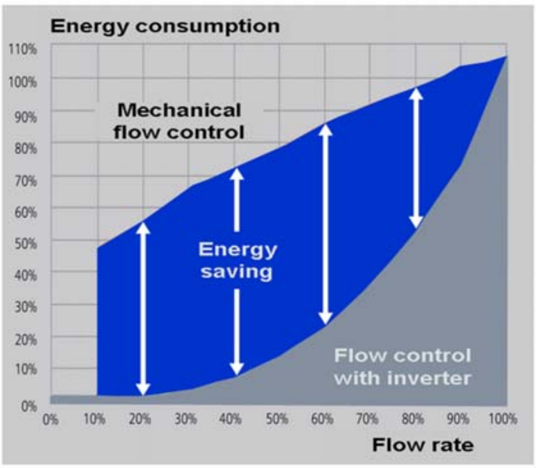

Fig. 4-8: Energy saving by using speed-controlled pumps instead of throttle valves

SINAMICS converters and inverters [16.] are available for energy-efficient drives in the low-voltage range:

- SINAMICS G110, G120, G130, G150
- SIMATIC ET200S FC and ET200pro FC
- SINAMICS S120, S150
- DYNAVERT T

and the medium voltage range:

- SINAMICS GM150, GL150
- ROBICON Perfect Harmony

Some of the drives such as SINAMICS G120, S120 and S510 have integral functions for regenerating energy during braking processes, so that valuable kinetic energy is not wasted as heat during braking, but fed back into the network.

4.4.3.2 SIRIUS Soft Starters

SIRIUS soft starters [17.] contribute to a reduction of up to 60% of mechanical and electrical peak loads and exhibit an extremely low internal power loss. Thanks to their measurement and communication capability, the "3RW44" soft starters and the "High Feature" motor starters can deliver energy measurement data to higher-level energy management systems.

4.4.3.3 SIMOCODE pro Motor Management System

Integrated into low-voltage switchgear, SIMOCODE pro [18.] for motors with constant speed in the low-voltage range is the intelligent link between higher-level automation system and the motor feeder – and ensures convenient, safe and trouble-free operation. The measuring functionality integrated in SIMOCODE supplies the energy measurement data required for energy management without the need for any additional cabling.

4.4.4 Energy-Efficient Motors

As mentioned above, about 70% of the electrical energy demand in industrial plants is required for drives. Siemens offers a comprehensive range of energy-saving motors in both aluminum and cast iron designs: [19.]. The portfolio covers voltages from 230 V to 13.2 kV as well as outputs of 0.09 kW to 100 MW and includes versions in various international classes of efficiency. Due to their design and the use of special materials, they offer efficiency factors up to 7% higher than standard motors.

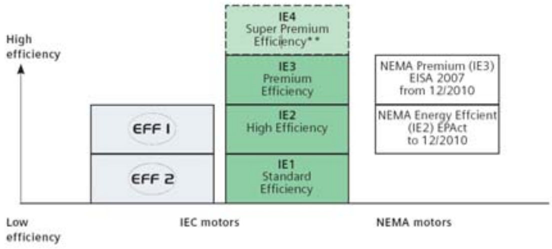

Fig. 4-9: New efficiency classes for electric motors according to IEC 60034-30

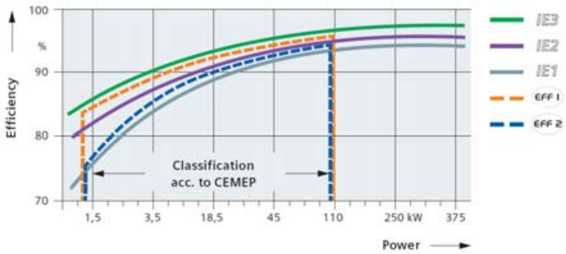

Fig. 4-10: Efficiency factors of electric motors; Source: [20.]

nergy-saving motors in accordance with the new international efficiency class standard IEC 60034-30 are available from 0.75 kW to the standardized limit of classification at 375 kW in the efficiency classes IE1 to IE3 – and for the North-American market in accordance with EPAct and NEMA Premium.

Siemens offers high-efficiency motors up to 690 V, both for line operation and inverter operation. Together with its subsidiary company Loher GmbH, Siemens offers an integrated spectrum of explosion-protected motors in the high efficiency class IE2, for Zone 2 and 1, in all common types of ignition protection and across the entire range from 0.75 to 375 kW.

4.4.4.1 SinaSave Software for Calculating Potential Savings in Drive Systems

The SinaSave [21.] energy efficiency software calculates on the basis of plant characteristics how high the potential savings are in a real drive application. SinaSave provides information on how quickly the investment in an energy efficiency motor will be returned in mains network operation or with a frequency converter for variable-speed operation. In mains network operation, SinaSave calculates the cost savings and amortization period of energy-saving motors in the high efficiency class IE2 or NEMA Premium – in comparison with motors of the standard efficiency class IE1 or EPACT, for individually selected motors or known motors within a consideration of the complete plant. In the case of converter-fed operation, SinaSave takes into account all the necessary plant-specific parameters as well as the values required for the process. SinaSave is available for downloading free of charge.

4.4.4.2 MOTOX Geared Motors

MOTOX geared motors [22.] in the performance range from 0.09 to 200 kW with all common types of gearbox feature high values for nominal torque and efficiency. The efficiency of the 1-stage helical, parallel shaft and helical bevel gearboxes is 98%; for the 2-stage gearboxes it is 96% and for the 3-stage gearboxes 94%.

For a positive energy balance sheet, Siemens offers high-efficiency geared motors in IE2 according to EU/CEMEP. 4-pole geared motors are designed in IE2 as standard. MOTOX geared motors up to 15 kW (4-pole) achieve IE1.

4.4.5 Stabilized Power Supplies

Power supplies in industrial applications are usually dimensioned to their maximum load, such as when switching on capacitive loads. In operation, they are mainly run only within a load range of 30% to 70% of rated power – dependent on the process, such as switching motors, sensors and actuators.

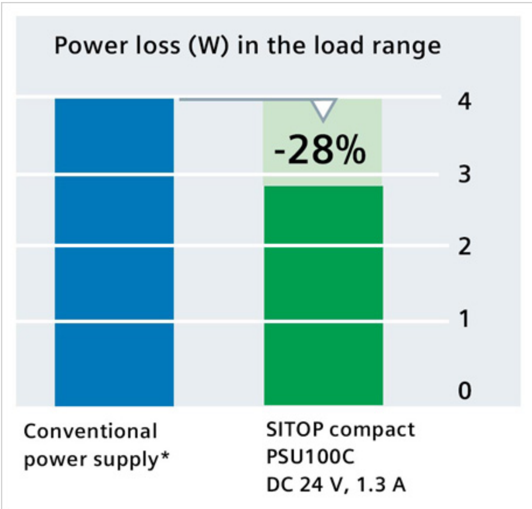

Fig. 4-11: Because of this, the high efficiency of the SITOP PSU100C across the entire load range saves up to 28% of energy compared to the average value of comparable devices on the market.

Stabilized power supplies such as SITOP [23.] offer numerous advantages over unstabilized power supplies: apart from a more precise output voltage and more efficient AC to DC conversion, SITOP primary synchronized power supplies also have a significantly high level of efficiency, thereby making them all the more impressive.

4.4.6 Energy-Efficient Electro-Pneumatic Positioners

Many control loops in process engineering plants, especially flow and pressure control loops, use continuous valves as actuators that are moved by an electro-pneumatic positioner. Compressed air, however, is one of the most expensive energy sources in such a plant. Air from the surrounding atmosphere must be compressed for this purpose and then purified of oil and particles to ensure the maximum service life of the components to be supplied. The compressed air thus becomes a relevant cost factor: The European Union Study "Save II" [36.] states that approximately 18% of the total energy of all industrial motors is used for generating compressed air. The largest cost component here of 65% is apportioned to the energy supply of the compressors themselves.

Taking into account the market-weighted shares of the positioners according to analyses, the average internal air consumption can be assumed for various types [35.]:

- Pneumatic positioners: approximately 1.18 Nm3/h (at 90 psig, approx. 6 bar)
- Analog electro-pneumatic positioners: approximately 0.69 Nm3/h (at 90 psig)
- Digital electro-pneumatic positioners tend to be even more economical, in the market-weighted average about 0.45 Nm3/h (at 90 psig), bandwidth from 0.02 up to 1.5 Nm3/h.

These potential savings in compressed air consumption are closely linked with energy costs and thus also directly linked with the CO_2 emissions involved in generating that energy. Taking account of the averaged specific energy requirement for the compressor of 6.38 kW•min/m^3 across the most varied sectors of the economy, an assumed specific CO_2 emission of 631 CO_2 g/kWh, and an assumed energy price of 6 ct/kWh, the following can be derived over one year for an average positioner:

- an energy consumption for compressed air generation alone of approx. 560 kWh,
- costs of approx. 34 Euros for compressed air generation alone,
- and CO2 emissions of about 354 kg.

The total potential savings for the total cost of ownership, however, only become apparent if, instead of looking at an individual device, you consider an entire plant in which from several hundred up to a thousand positioners are operated over a period of decades. Thus, 1000 average positioners generate 3,500 metric tons of CO_2 over 10 years. If you want to exploit these potential savings, you simply cannot avoid positioners with low air consumption characteristics.

Siemens has the portfolio of positioners with the lowest air consumption. A Sipart PS2 has an impressively low consumption of just 0.036 Nm3/h. Extrapolated to one year, this produces the following values:

- an energy consumption for compressed air generation alone of approx. 33 kWh,
- costs of about two Euros for compressed air generation
- and CO2 emissions of about 21 kg.

In addition, the compressed air consumption during operation crucially depends on the setting of the higher-level PID flow or pressure controller that controls the valve: The more aggressive the controller setting and the broader the measurement variation, the greater the operating movements of the controller actuating values will be and thus the traveling distance covered by the valve using compressed air. The compressed air consumption can differ by a factor of between 2 and 5 for different settings of the controller parameters. In each case, therefore, it is worth commissioning each PID controller carefully, e.g. with the aid of the Simatic PCS 7 PID tuner.

5 Services for Energy Efficiency in the Production Process

5.1 Professional Services Energy Management

The central contact for energy efficiency services in the production process in the Industrial Automation Division is the "Professional Services Energy Management" department in Nuremberg.

It offers product-independent consulting and supports the use of products based on standard technologies. For example, the visualization of energy data is based on process visualization. In this way, investments can be kept to a minimum and the products have an assured future. Specifically, the use of SIMATIC powerrate and B.Data is supported by the consultation activities.

If required, contact can be established from this central hub to numerous industry experts from the Siemens group, such as experts in energy optimization in process engineering plants, see Section 5.3.

5.2 Energy Management for Industry

Under the heading of "Energy Management for Industry" [26.], the Siemens "Industry Solutions" Division offers a package of scalable system solutions that are combined and integrated into plants according to customer requirements. These systematically support the actions of plant operators aimed at continuous improvement and raising energy efficiency.

In the context of the SIMAIN energy optimization, the entire energy balance sheet of the company is analyzed and all forms of energy, including electrical, mechanical and thermal energy, as well as all the energy resources used, such as oil, gas and water, are considered. The SIMAIN energy optimization is divided here into four phases: An Energy Health Check identifies potential for optimization by means of a two-hour, computer-aided interview with key people in the operation; the evaluation of this information then permits benchmarking with other companies in the same industry. This is followed by a technical analysis for estimating the actual energy savings possible. A typical starting point is the provision of auxiliary energies such as compressed air and process steam in ancillary units. It is possible to optimize here without affecting the actual production process. A further idea that often shows promise of success is the use of waste heat at other locations in the process.

Taking into account the ROI and feasibility, an individual concept is then drawn up in the third stage. Finally, there is support of the sustainable implementation of these measures.

The consultation can also extend to energy procurement (contracts with suppliers), the procurement of public subsidies for energy-saving measures and the trading of CO_2 certificates.

5.3 Consulting for Saving Energy in Process Engineering Plants

In process engineering plants the energy consumption for process heating or cooling dominates other, particularly electrical, energy consumers, so that measures for optimizing the core engineering process offer the greatest potential for savings.

As part of process engineering optimization in terms of energy in chemical and pharmaceutical plants with their columns, reactors, pumps and heat exchangers, an energy study [27.] is produced.

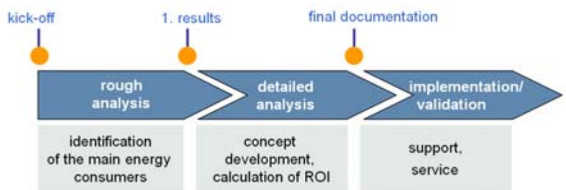

Fig. 5-1: Typical sequence of process engineering energy optimization

An energy study consists of three stages: The rough analysis delivers the first results in the form of ideas for potential savings. In the detailed analysis, the experts develop actual optimization measures from these ideas and calculate their return on investment (ROI). The customer receives all the results as comprehensive final documentation. If the customer has decided on one or more projects, the last stage comprises the installation or financial controlling that the consultants manage and support.

The rough analysis begins with preliminary work and the "kick-off". This includes intensive discussions with the customer, in which the team from Siemens uses plans, consumption data from the past twelve months and energy supply invoices etc. to obtain an initial overview of the site and its production processes – the more information, the better. Customer and service provider jointly specify which aspects of the study should be considered, draw up a schedule and define the project team (project manager/contacts). The rough analysis itself begins with the presentation of the objective and purpose of the study and a tour of the plant. In order to be able to assess the project, the business partners define a reference for evaluating possible savings. One potential scenario: The management plans to save 10% of energy costs over the next two years.

This is followed by an appraisal of the current situation and a detailed analysis of the individual consumers. If particular information is missing, the engineers themselves get to work and determine the consumption figures by means of thermodynamic calculations. In collaboration with the customer, a detailed energy study is gradually created. The experts gather ideas and project sketches that are all fed into an evaluation matrix. In many plants, an holistic consideration can throw light on dormant synergies. On the basis of their extensive experience from numerous projects, the employees usually know which plant sections are the greatest "energy guzzlers" and cost drivers.

In many cases, minor conversions help to save a considerable amount. A prime example of this is unused exhaust air and waste heat. For example, a latent heat storage unit could hold waste heat and use it when required for heating buildings.

On the basis of the assessment matrix, customer and service provider can prioritize those projects that are to be considered in the detailed analysis, and create a corresponding catalog of measures. This "to-do list" can still be worth hard cash even many years later, for every investment that perhaps does not pay for itself today, may be profitable tomorrow due to rising energy costs.

One example of energy optimization in continuous processes is thermal integration based on a pinch analysis, with the aid of which the thermal integration of many generators and consumers can be optimized and further measures can be derived. Material flows that require cooling and heating can be sensibly connected via a heat exchanger network. Feed preheating/cooling for reducing the energy demand of columns, waste heat steam generation and the use of heat pumps/exhaust vapor compression are also worthy of examination. For batch systems, the pragmatic network method (variable time) is the better path. This means searching for those connections that lead to a maximum internal recovery of heat. The boundary condition applies that each flow is switched only once. Alternatively, heat or cold storage units can be used.

Examples of measures for saving energy through process optimization:

Mechanical (intelligent apparatus design):

- When heating or cooling by means of recirculation, small and efficient plate heat exchangers offer many advantages over tubular heat exchangers.
- The design/construction of condensers (type: tubular heat exchangers) and the feeder parts to a column are among the typical "weak spots".

Utilities (auxiliary materials, service media):

- Substitution of expensive media such as freezing brine or high-pressure steam with process improvements and thermal integration (pinch technology).
- In the past, many items of apparatus were over-dimensioned. Astonishing results can often be achieved with minor modifications to the operating conditions.
- A further proven means of energy optimization is to improve the efficient use of condensate (thermal integration).
- The distribution of pressure loss in the cooling water network can also be calculated and minimized by optimum connection of the apparatus.

Operating procedures:

- Check cooling and heating processes in containers.
- The efficiency of the heating and cooling processes can often be increased by using flow nozzles.

Process:

- Energy-intensive crystallization processes can be precisely controlled according to measured or calculated material properties.

- Quality control in reactors and distillation columns so that not the best possible quality is produced, but the quality that meets the specifications and can be manufactured most economically.

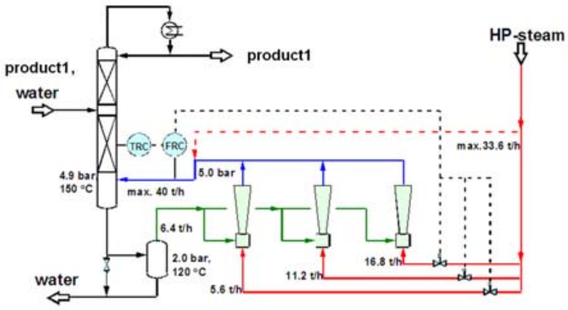

Fig. 5-2: Use of a steam jet to reduce the high-pressure steam demand during separation of water and product1

Example of a project involving a distillation column: Additional formation of steam by decompression and use of steam jets reduces the high-pressure steam requirements by about 6 metric tons/hour, representing a saving of €500,000 per year and paying for itself within a few months.

6 Outlook

Technical development goes on and a series of innovations that will bring new opportunities for optimizing energy use can already be discerned.

6.1 Universal Data-Driven Optimization

In many process plants there is still potential for improving energy efficiency by optimizing process control, i.e. without expensive mechanical or process engineering revamps, without additional heat exchangers or new pump drives. In order to track down this potential and leverage it, the approach of universal data-driven optimization [28.] can be employed.

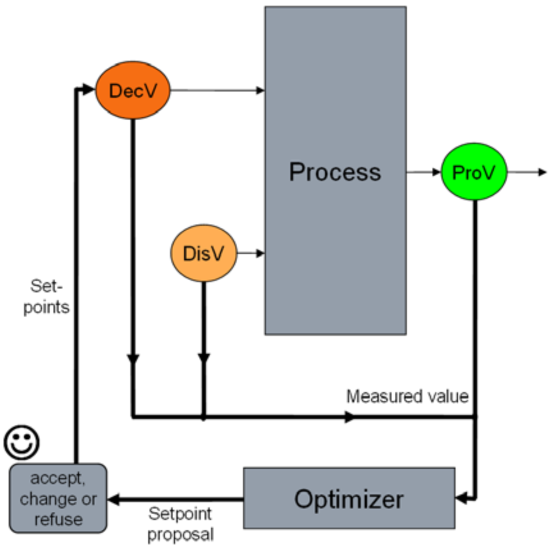

Fig. 6-1: Universal data-driven optimization, DecV: Decision Variables, DisV: Disturbance Variables, ProV: Process Variables

"Universal" in this context means that every type of process plant can be optimized and every type of formulation of the performance index (target function) is possible. The procedure is suitable not only for linear, but also for non-linear processes, for batch as well as continuous processes. Depending on their production plant, users can specify any optimization target in the form of a performance index to be optimized.

"Data-driven" means that the optimization procedure uses current process data. It is not necessary to create a process model before starting the optimization. The process model is determined step by step during the optimization from current measurement data. From this, it follows that no complete process model is available to the optimization procedure, but only a partial model of the process in the environment of the current operating point.

The models are static models, i.e. they describe the process in a steady state condition. All process variables that can be modified directly by the plant operator by specifying setpoints are designated as process inputs. They are considered as decision variables (DecV). In addition, all variables that influence the process and can be recorded by measurement instruments, but cannot be modified by the plant operator, are likewise considered as process inputs, e.g. as measurable disturbance variables (DisV). All variables that vary according to the decision variables and disturbance variables are considered as process variables (ProV).

During the optimization, constant constraints are considered for all decision variables and process variables, as well as linear and non-linear constraints for the decision variables. The calculated values are initially displayed as a proposal for new setpoints for the decision variables and can be corrected by the user. These proposals are then transferred to the process as new setpoints.

One fundamental principle of data-driven optimization is that it operates step-by-step, i.e. on a sequential basis. In other words, current measured values are first read by the process, from which a data record is created. The modeling then takes place on the basis of all captured data records and then the optimization, during which a new step proposal is generated. Once this has been forwarded to the process, it is necessary to wait until the process has leveled off, i.e. a steady state condition has been attained. A new data record is then read.

Typically, during process operating a local optimum is reached after 20 to 50 iteration steps; this exhibits a significantly better value of performance index than the original plant operating point. The potential for savings in a real application greatly depends, of course, on the tolerance of the decision variables.

A software prototype for universal data-driven optimization by means of OPC interface to a PCS 7 Operator Station is available for pilot tests.

6.2 Smart Grid

The term "Smart Grid" ([29.]) covers the communicative networking and control of power generators, accumulators, electrical consumers and network resources in energy transmission and distribution networks of the electricity supply system. This allows the optimization and monitoring of the interconnected components. The integration of increasing quotas of volatile energy generation from regenerative sources (photovoltaic, wind energy etc.) with distributed infeed demands a network infrastructure that offers dynamic adaptation.

Fig. 6-2: Smart Grid with distributed cell structures, Source: E-energy project "Model City of Mannheim"

The operator of a process engineering plant will in future no longer be the energy consumer, but the energy "prosumer" (= producer and consumer), i.e. an active participant in the energy market. They will have their own opportunities for power generation (e.g. combined heat and power plants, solar collectors), for active control of their own energy demand and feeding into the public energy network, and they will use this degree of freedom to economic advantage, depending on the current situation in the energy market.

The collaboration between the different fields of technology at Siemens along the energy flow chain forms the basis for future Smart Grid solutions for energy distribution: [31.].

6.3 Coordinated Deactivation of Consumers with PROFIenergy

A further key to reducing energy costs, especially in the field of discrete production, is offered by PROFINET: the deactivation of consumers not required during breaks in production.

For this purpose, PROFIBUS & PROFINET International (PI) has developed a standardized data interface based on PROFINET: PROFIenergy [24.] enables consumers, regardless of the type and manufacture of device, to be switched off centrally in a coordinated manner. This does away with time-consuming manual switching and enables energy to be saved even during short breaks.

By means of the PROFIenergy-compatible power module of the ET 200S, as well as function blocks in the controller, existing hardware and software can easily be integrated into the energy management via PROFIenergy. In connection with the PROFINET functionality "I device", PROFIenergy also allows the coordinated shutdown and start-up of complete sections of the plant. The reloadable function blocks ensure low configuration overheads.

6.4 PLM Software (Product Lifecycle Management)

The Siemens PLM software [30.] also includes the Comos system for the CAE planning of process engineering plants. In simulated examinations as part of the basic process engineering, essential specifications regarding material and energy flows in the plant have already been made. If it is possible to keep this information accessible through the detail engineering up to the operating phase of the plant by means of an integrated use of models, it can be used to advantage within the scope of an energy management system.

6.5 Use of Residual Heat

One obvious approach is the use of residual heat at other locations in the same process, or for heating nearby administration buildings. Relatively low supply temperatures are required for heating buildings, so that even residual heat that can no longer be used for steam generation is suitable.

It is also conceivable to use residual heat for the generation of coolant in an absorption cooling machine.

Innovative technologies that are being developed in the geothermal field could possibly allow residual heat that escapes unused today to also be used in process engineering plants in the future. Although the technologies listed below have been known of for some time, they are continually being optimized:

- Kalina process [32.]: Procedure for the generation of ammonia-water vapor at a low temperature. In order to make use of geothermal water at low temperatures, possibly even below 100 degrees Celsius, the Russian engineer Kalina developed a cycle whereby the heat of the water is passed to an ammonia-water mixture. The steam that is generated even at considerably lower temperatures from the ammonia-water vapor is then used to drive turbines.
- Organic Rankine Cycle [33.]: Procedure for operating steam turbines with a working medium other than water vapor. Organic fluids which have a lower vaporization temperature are used as the working medium. The procedure is used primarily where the available temperature gradient between heat source and sink is too low for the operation of a steam-driven turbine.
- Residual heat use with salts (e.g. sodium acetate = pickling salt) [34.]: The residual heat is used for dissolving the salt and can be released at another time and place when the salt crystallizes.

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