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Totally Integrated Power

Applications for power distribution

Energy transparency

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Contents

Energy transparency

The basis for efficient electric power distribution is appropriate planning combined with demand-oriented dimensioning of products and systems. Customers and approval authorities increasingly focus on operation-related energy consumption. And last but not least, contractors are required to comply with standards concerning energy management (ISO 50001) and energy efficiency (IEC 60364-8-1; VDE 0100-801).

Without a comprehensive understanding of the energetic correlations which define energy transparency, there is no basis for operational efficiency evaluations and for energy management. So it is imperative to provide for measurement and analysis of the electric power distribution system during planning. In this context it is useful to distinguish between

- Power sources (such as transformers and generators)
- Connecting lines (such as cables and wires, busbar trunking systems)
- Protection and switching systems (such as switches, circuit-breakers, contactors, fuses)
- Loads (such as luminaires, frequency inverters, motors, pumps, power supply units)

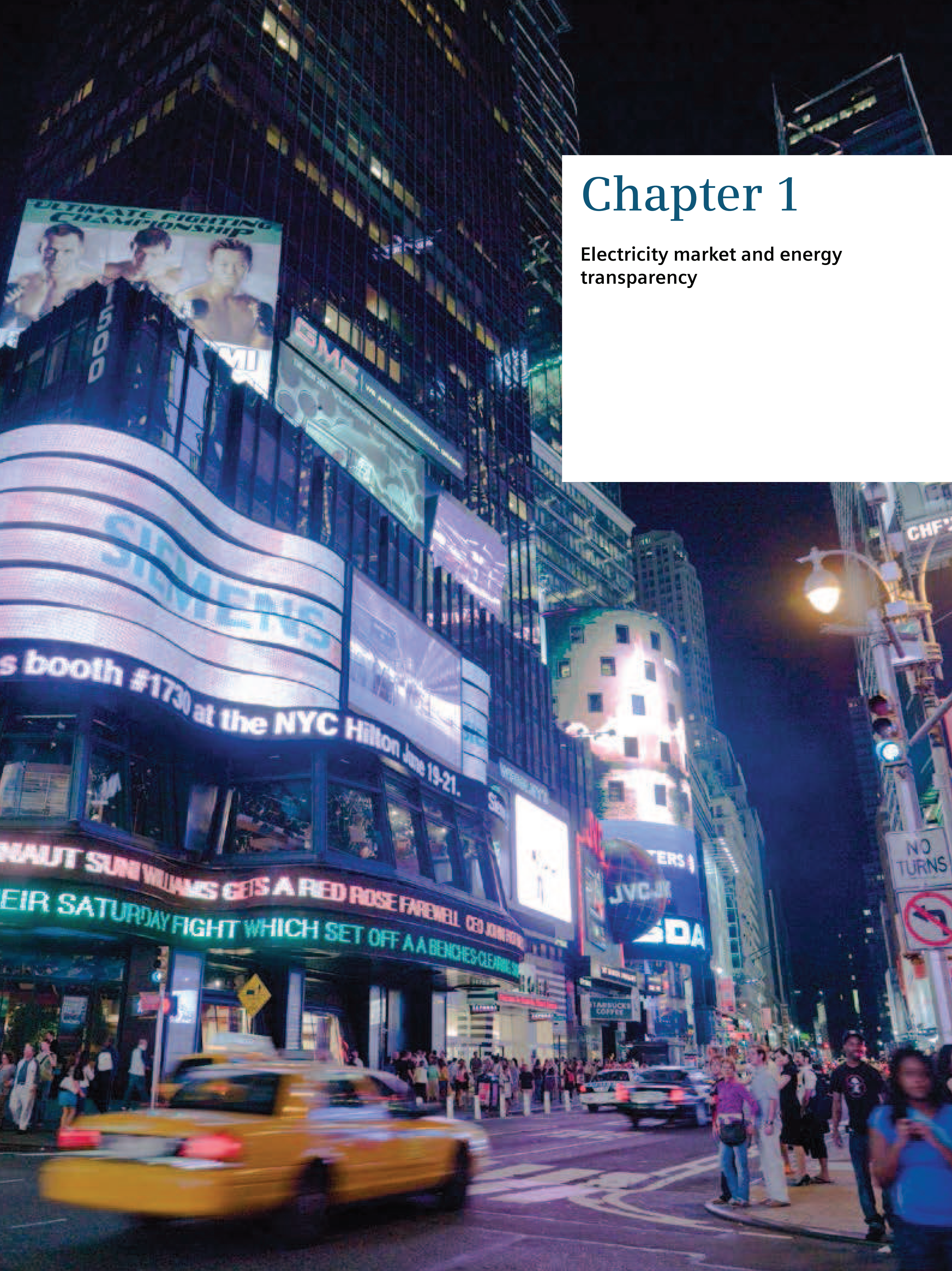
Measuring instruments, data storage media, and a suitable analysis system (hardware and software) are important aids which must be smartly employed as to attain the level of energy transparency required in normal operation. The following might contribute to achieving this goal:

- Data acquisition of power consumption
- Utilization profile over time
- Voltage quality for power consuming equipment and load interference on the supply grid
- Comparisons of actual and target values
- Signalling (for example by warnings and alarms)

Therefore, integration of modern instrumentation should be a constituent part of planning, and the resulting energy transparency can provide the plant with an additional competitive edge. This application manual explains characteristic terminology, describes the structural design of a task-specific measurement system, introduces and compares typical features of measuring instruments, and demonstrates their use in a number of examples for various applications.

Chapter 1

Electricity market and energy transparency



1 Electricity market and energy transparency

Economic efficiency plays a particularly important role in the commercial use of buildings. Recently it has become apparent that operational energy costs are a significant cost factor (Fig. 1/1). Cost reductions have become possible in the liberalized electricity market thanks to aggressive corporate procurement management. As a result of the energy turnaround which is accompanied by an increasing use of renewable energy sources whose availability depends on greatly varying environmental conditions, the availability of the commodity 'electricity' has tended to be more incalculable so that the interplay of electricity supply and electricity consumption is becoming increasingly important.

In the future, favourable purchase conditions for electricity will increasingly depend on the predictability and flexibility of consumption. In the electricity supply contract between consumer and electricity supplier, the different components of electricity consumption such as base peak and offpeak as a function of time blocks (Fig. 1/2) are stipulated:

- Base: continuous electricity consumption for one day; for a year the individual base day values may be specified (one unit corresponds to 24 MWh/d)
- Peak: daily electricity consumption between 8 a. m. and 8 p. m. (one unit corresponds to 12 MWh/d)
- Offpeak: Electricity consumption of 1 MWh for one hour at any time

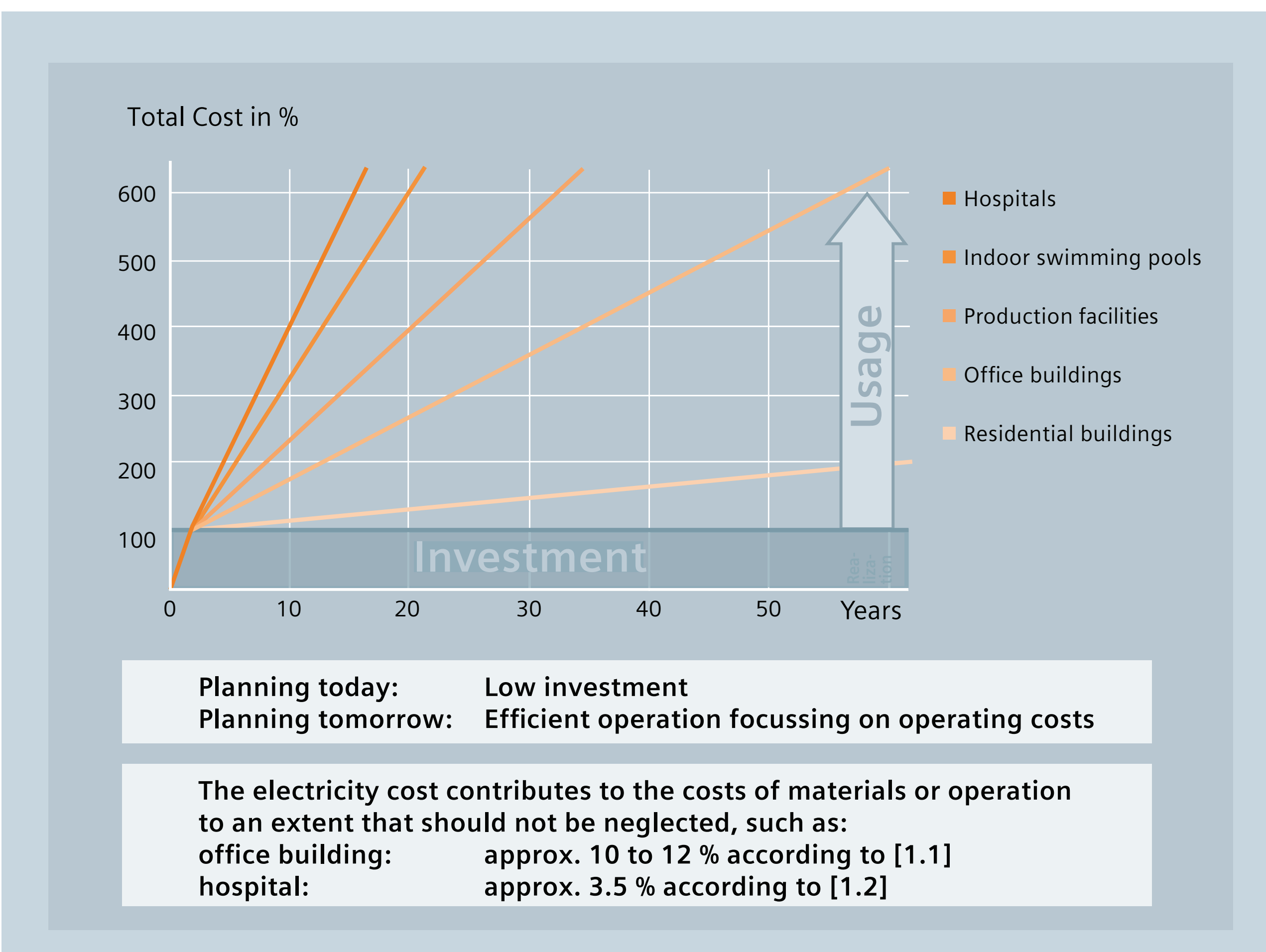


Fig. 1/1: Cost of operation and investment for some building types

Quarter-hour based purchase contracts of energy consumers with an annual consumption of more than 100,000 kWh/a, may require demand forecasts on a 15 min basis. Time requirements and options for optimization are diagrammatically compiled in Fig. 1/3.

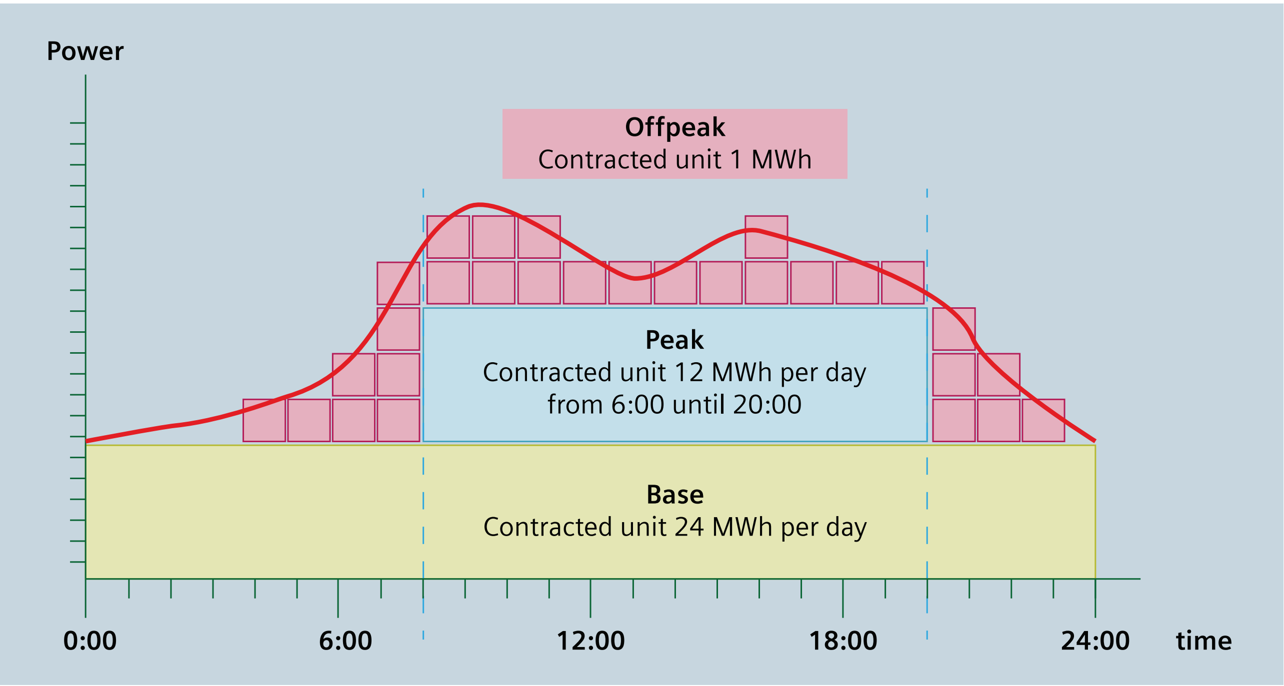


Fig. 1/2: **Contract modules in electricity trading**

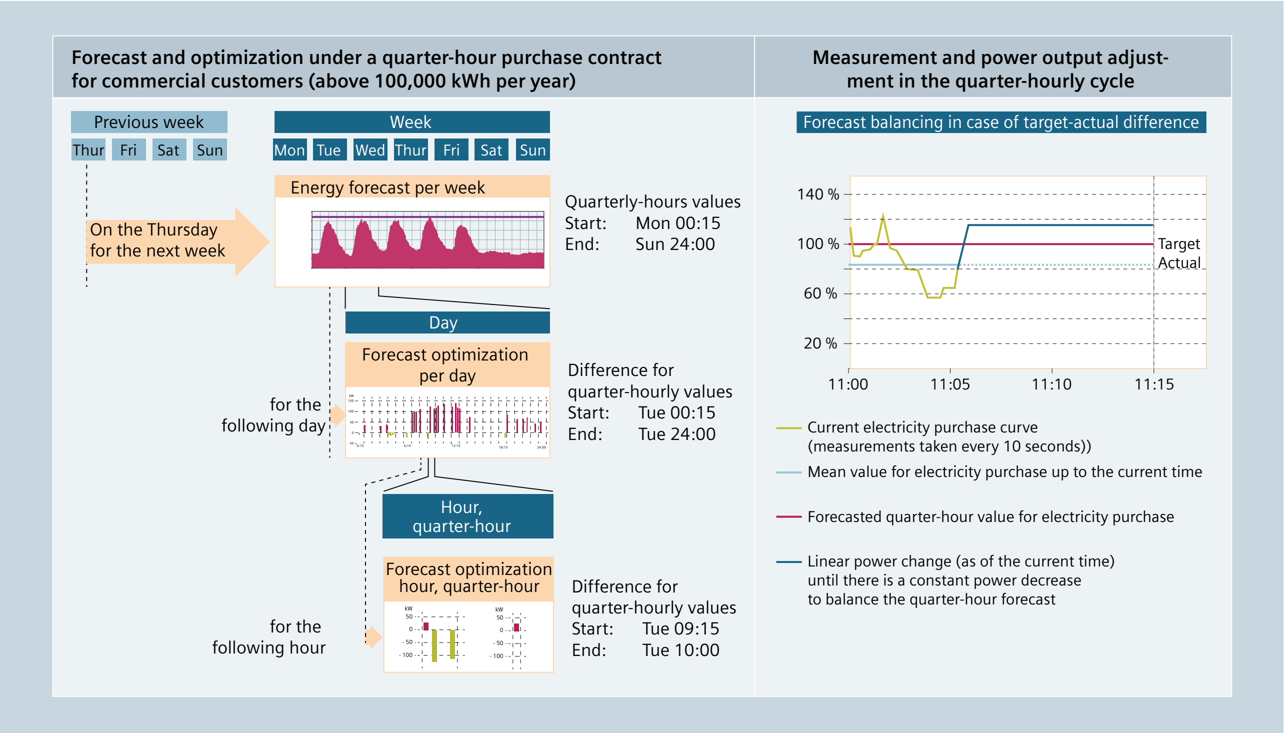


Fig. 1/3: **Time schedule for forecast optimization and limit monitoring for meeting forecast volumes**

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For this purpose, the consumer must submit a quarter-hour based forecast of his power demand to the electricity supplier in advance. The forecast covering one week from Monday through Sunday must be provided on the Thursday of the previous week (Fig. 1/3). Forecast optimizations may, however, be submitted for individual days, hours, and even quarter-hours at the agreed times (following day, following hour, ...) as diagrammatically shown in Fig. 1/3. This involves the corresponding contractual stipulations.

Within the current quarter-hour, it is the consumer's responsibility to ensure compliance with the submitted forecast by way of load management. In accordance with a priority list set up by the consumer, loads are connected into and disconnected from supply or controlled to balance the difference between target and actual power. For extrapolations of the quarter-hour energy value, the forecast must be checked at short intervals (typically 10 seconds) (Fig. 1/3) and adjusted if necessary.

Continuous transparency of system operation is the prerequisite for ensuring a long-term cost-efficient, safe, and reliable energy supply. Minimizing electric power consumption by a use-related optimization at the planning stage and when installing the system is a standard requirement which has been postulated in IEC 60364-8-1 (VDE 0100-801). Thus energy transparency ensures the efficiency of power systems in a smart way enabling, as a result, the operation of a smart grid.

If consumers generate electricity themselves, be it for their own use or for feeding it back into the distribution grid, then the consumer's own power system becomes a "micro grid". In the Micro Grid an orderly or even an optimized mode of operation is not feasible without reliable forecasts of consumer-related power demand.

The flexibility inherent in the Micro Grid also allows trading in electricity. If balancing power is made available to transmission grid operators for a quarter-hour period, this may – dependent on response time and market conditions – be even remunerative for the power generating entity.

- Primary balancing power (PBP, primary control):
  Immediate response,
  100 % balancing power after 30 seconds
- Secondary balancing power (SBP, secondary control):
  Initial response within 30 seconds,
  100 % balancing power after 5 minutes
- Tertiary balancing power (TBP, tertiary control):
  First response after 5 minutes,
  100 % balancing power after 15 minutes

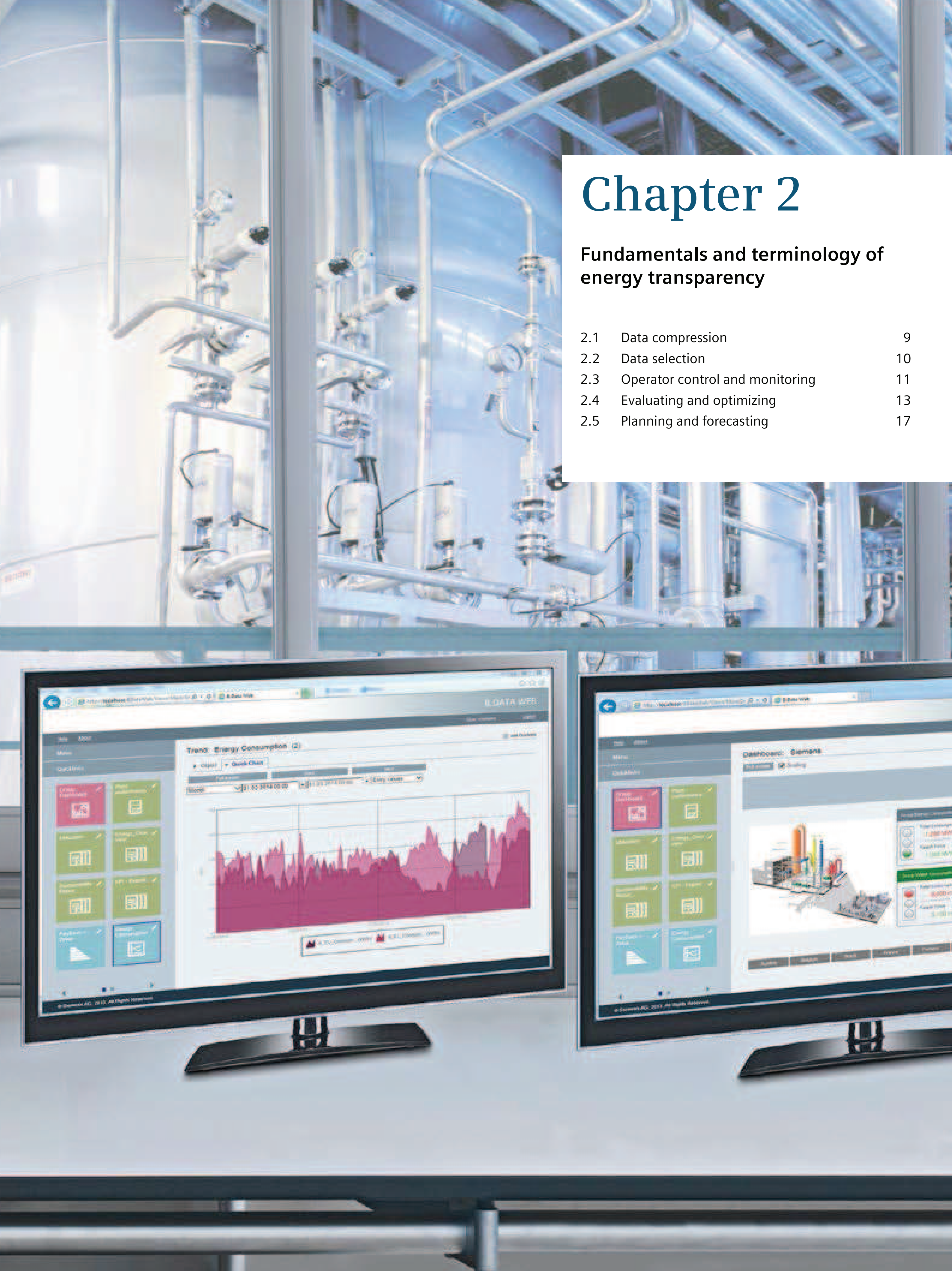
The balancing power market manages positive and negative balancing power volumes. The transmission grid operator requires these for his contractually stipulated system power. At present, the transmission grid operator directly accesses the generating units provided by the consumer. Metering is done unit-related; load control is performed by telecontrol.

Note: This access "from outside" creates a conflict of objectives for the consumer. If the consumer wants to fulfil his forecast as accurately as possible, what he needs is flexibility. If this flexibility is, however, needed to safeguard balancing power, voltage stabilization, or balancing group loyalty (see chap. 3), this will be to the detriment of the consumer's forecast fulfilment.

Forecasts are increasingly becoming the main constituent of optimization, both in terms of the purchasing and the supply of electrical energy. Only when the consumer is aware of his own demand of electricity and the grid conditions, can power generation/power transformation and power import into the Micro Grid be planned and optimally used. The prerequisites for this transparency are measurements and their evaluations as specified below.

Chapter 2

Fundamentals and terminology of energy transparency



2 Fundamentals and terminology of energy transparency

Electrical engineering deals with measuring current and voltage. Systems employed in metrology such as meters, circuit-breakers, protection devices, and multi-function meters are able to deduce additional parameters (Fig. 2/1) from these measurands (see section 2.1), for example power P as a product of current and voltage:

$$P = U \cdot I$$

Note:
For the purpose of simplification, we are actually dealing here with a vector multiplication, where the phase angle φ between voltage and current should be factored in as cos φ.

Since time-dependent parameters are examined (such as the voltage characteristics in Fig. 2/1), the display of a measured value reflects the present actual value. Therefore, it is necessary to record measured quantities for processing and evaluation. A meaningful timing cycle for measurements results from the fluctuation of the measured quantity. In order to detect changes within the millisecond range at all, a minimum of 5,000 readings per second or more is required. Readings at intervals of 0.2 ms and their recording thus correspond to a scan rate of 5 kHz, from which large data volumes may result.

In order to reduce such large data volumes, two methods can be applied and combined:

data compression and data selection

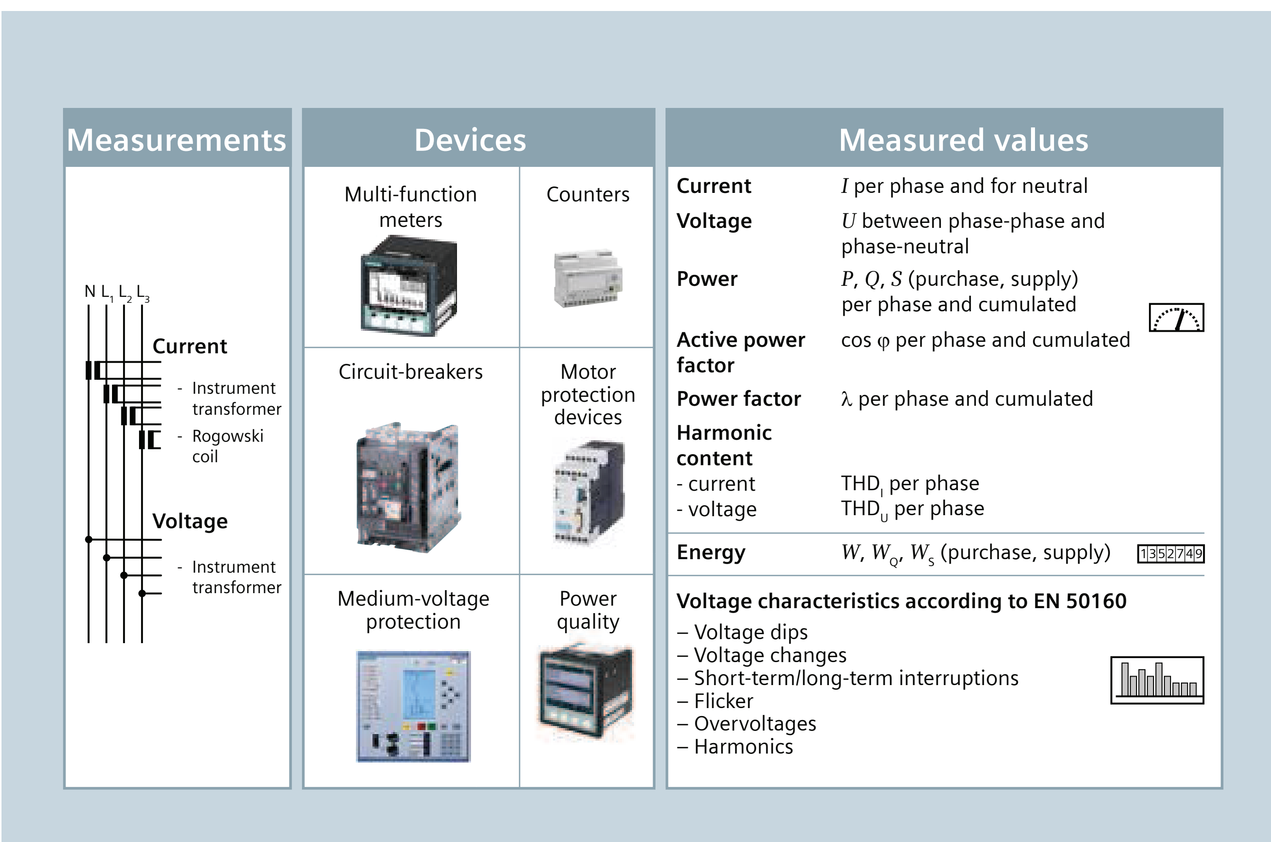


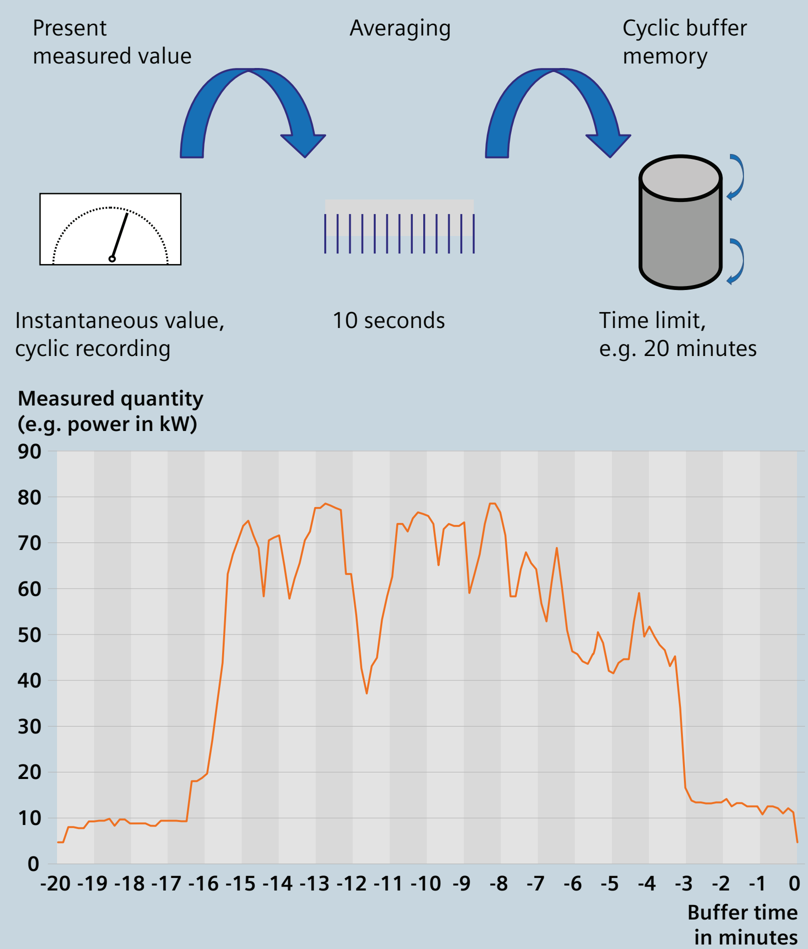
Fig. 2/1: **Electrical measurements, measuring instruments, and measured values (for the explanation of symbols see Annex 8.2)**

2.1 Data compression

During data compression, measured values are averaged and only the mean value is selected and recorded, for example for analysis and evaluations covering longer periods of time. 10-second cycles have turned out to be a practicable interval for operating and monitoring. For further processing such as data visualization and event recording, these 10-second values are kept in a cyclic buffer memory for 20 minutes (Fig. 2/2).

All energy billing, forecasting, and monitoring is based on quarter-hour values. Consequently, those recorded 10-second cycles are further condensed into 15-minute values and saved.

When statuses are recorded, it is sufficient to compile status changes together with their associated time stamps. For a more precise evaluation, values from the cyclic buffer memory may also be output on a case-by-case basis.



An event such as a warning or a fault can trigger storage in the cyclic buffer memory for 20 minutes. This means that measured values of voltages, currents, or power factors, for example, can be used for further evaluations.

Fig. 2/2: **Data compilation and storage**

2.2 Data selection

For the purpose of data selection, selection criteria are required as to which information is to be compiled and recorded. Instant signalling of status and operational changes as well as faults facilitate prompt interventions of the operating personnel. Furthermore, a subsequent analysis of recordings of incidents often allows important conclusions to be drawn about characteristic causes and requirements.

For easier data use, the recorded measured values are post-processed for one of the three task-specific views:
• Monitoring and operating (Operating)
• Evaluating and optimizing (Controlling)
• Planning and forecasting (Managing)

There are views with typical content and graphics to suit each of these three core tasks (Fig. 2/3). In addition, there are further calculations and compilations of tabular and/or graphic analysis.

The process of information compression from monitoring to planning also clearly illustrates the transition from energy transparency to energy management. The following sections describe user views which are usually suited for an appropriate evaluation of measured values.

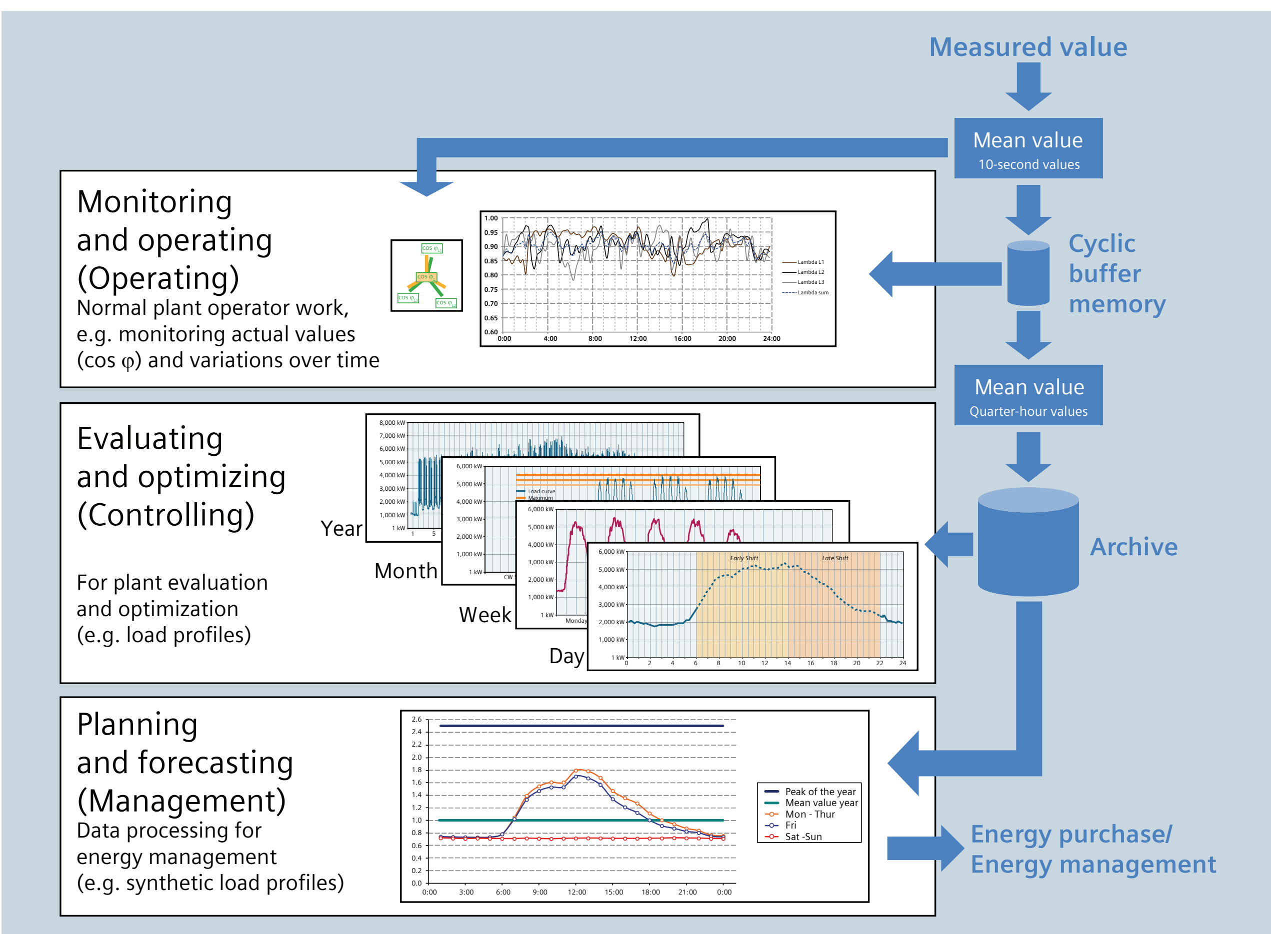


Fig. 2/3: **Post-processing of measurement data**

2.3 Operator control and monitoring

A characteristic representation of the current status of electric power distribution involves the display of measured values as well as switching and function statuses. In order to make them more transparent, it is useful to integrate them into a schematic diagram of the power distribution structure as a single-line diagram. Fig. 2/4 combines all of the three types of graphic representation.

- Display within the distribution structure:
  Single-line diagram, from which the various measurement and monitoring locations can be called up; individual measurands may also be locally displayed
- Status indication:
  Shows the status of a protection device; an active user interface of a software allows switching operations to be initiated
- Measured value indication:
  Actual-value representation of measured quantities such as voltage, current, active power factor cos φ, or power factor λ; the data refresh interval must be set as a function of the performance of the measuring instruments and storage devices

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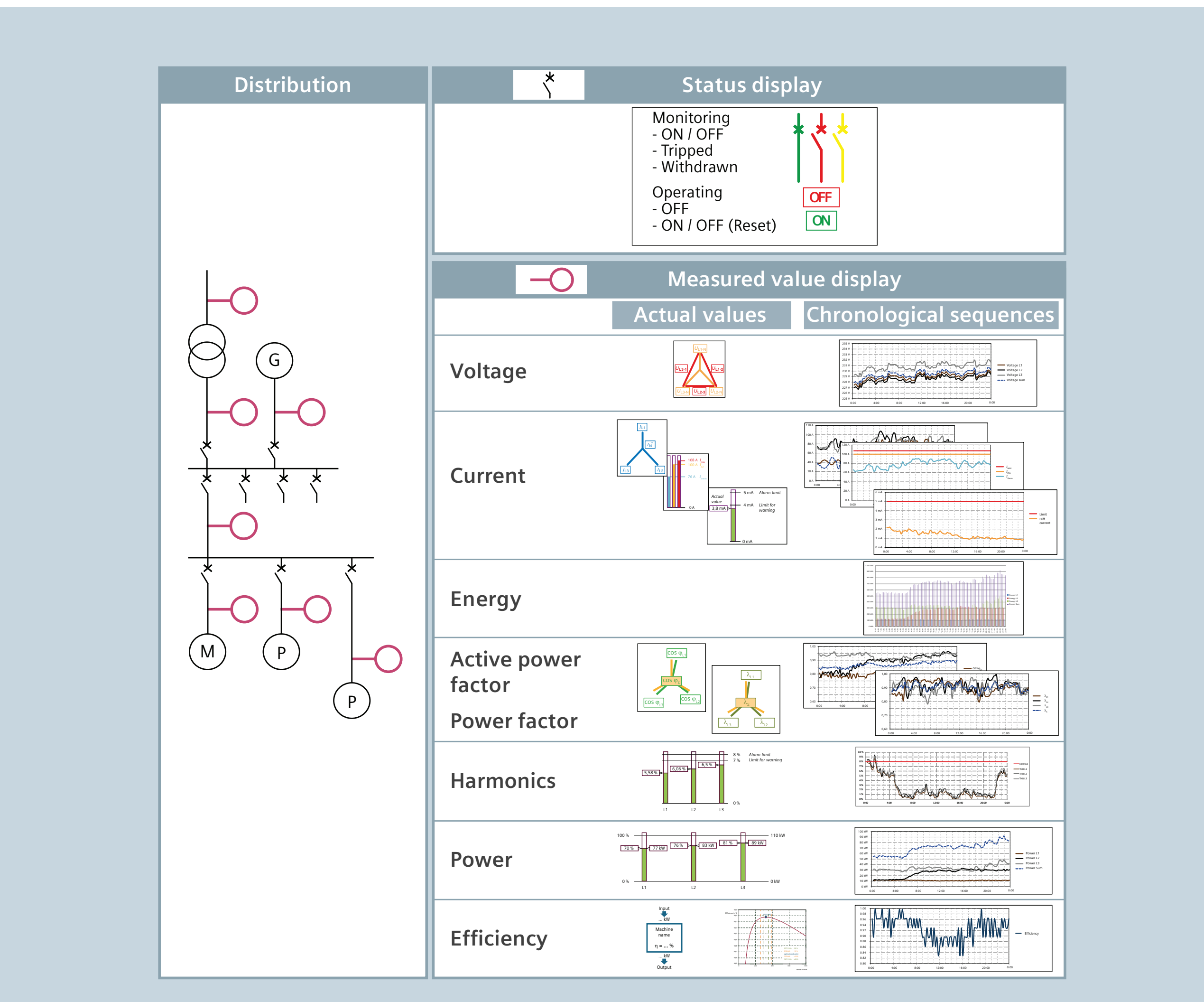


Fig. 2/4: **Display elements for status and measured value indication**

Typical views are:
- Indication of the switching status of switching and control devices
- Indication of the operational statuses (test position, pushed in, withdrawn)
- Voltage indications
- Current indications
- Indication of cos φ and power factor
- Indication of power and energy values
- Instantaneous-value indications of efficiency or losses (efficiency)
- Graphic representations of harmonic response

Examples of which information is to be gained from various measured-value displays in accordance with IEC 60364-8-1 (VDE 0100-801) are listed in Tab. 2/1. It may be necessary for the operating personnel to simultaneously monitor actual values, have an overview of a certain trend and view the indication of limit-value violations. For this reason, it should be possible to combine various views in a flexible way and adapt them to the task setting. Comparative diagrams, area enlargements, scale settings, and limit-value marking are only some examples of how flexible display options may support the user.

2

Parameter to be monitored	Monitoring / Check / Adjustment
- Energy W	- Energy cost - Transparency of energy flow
- Power P / Current I	- Utilization (drives and motors by means of power; power system components such as cables, wires and devices by means of phase and neutral currents) - Evaluation of equipment characteristics and protection settings of devices (degree of utilization; overload; power system reserves; idling power; ...
- Protective earth conductor current I_{PE}	- Adhering to the tolerable PE currents in compliance with IEC 61140 [1)] (in particular for critical applications such as data centres)
- Residual current I_{diff}	- Meeting EMC requirements for the power system (in particular for critical applications such as data centres)
- Voltage U	- Maintaining the voltage quality in compliance with EN 50160 (±10% deviation from U_n)
- Active power factor cos φ	- Meeting value ranges as agreed in purchase contracts, e.g. $\cos \varphi \geq 0.9_{ind}$ (a capacitive total load is not permitted) - Identification of individual items of power consuming equipment which deviate from the permissible value range - Starting point for rating power compensation
- Power factor λ	- Comparison with cos φ allows information about harmonics to be derived
- Harmonic content THD_I	- Identification of equipment which generates harmonics
- Harmonic content THD_U	- Adhering to the limit value for the total harmonic distortion (THD) in compliance with IEC 61000-2-12 (VDE 0839-2-12) of 8% ($THD_U \leq 8\%$)

[1)] Protective earth conductor currents in compliance with IEC 61140:

Rated current of equipment	Maximum PE current
$0 < I \leq 2$ A	1 mA
$2 \text{ A} < I \leq 20$ A	0.5 mA/A
$I > 20$ A	10 mA

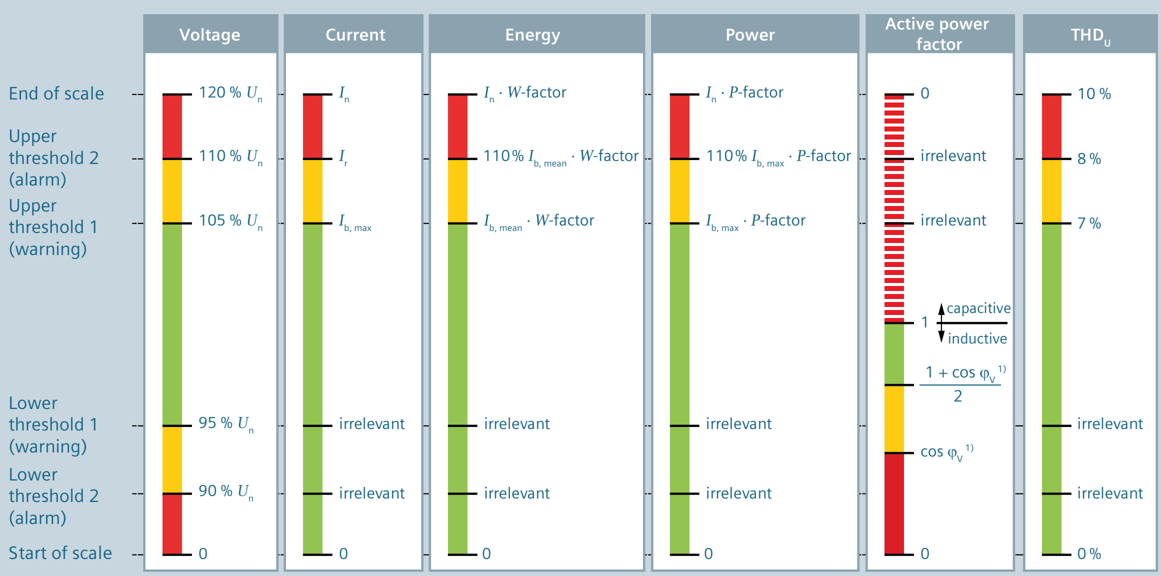
Tab. 2/1: **Benefits from monitoring various electrical parameters of power distribution**

Generally speaking, a scaling of measured values corresponding to the display size is indispensable for user-friendly data representation. For the purpose of signalling, thresholds for warnings and alarms may be entered, and limits being exceeded could be indicated by colour-coding or a sound signal (Fig. 2/5). Warning and alarm thresholds for exceeding or undershooting the permissible value range could be entered in the voltage section, for example. According to EN 50160, deviations up to ±10 % from the nominal voltage are permitted so that

- a warning makes sense in case the voltage is exceeded by $1.05 \cdot U_n$ / or undershot by $0.95 \cdot U_n$ and
- an alarm will be issued in case of $1.1 \cdot U_n$ / $0.9 \cdot U_n$.

2.4 Evaluating and Optimizing

Whereas momentary time profiles are only displayed to give up-to-date information for plant operation, longer periods intended for evaluation are displayed as graphs or bar diagrams. A compilation of characteristics in tabular form may also help the assessment. The objective of evaluation to be demonstrated is important for the choice of view or for the compilation of characteristic parameters: conditional upon, for example, the weekday, holiday times, shift periods, seasonal weather conditions, and so on.



Legend:

I_n = Nominal current
I_r = Rated current of electrical equipment
$I_{b,\,max}$ = 10-second value for the maximum operating current
$I_{b,\,mean}$ = 15-minute mean for the maximum operating current
U_n = Nominal voltage
cos φ_V = Contractually agreed minimum inductive active power factor

P-factor $= \sqrt{3} \cdot U_n \cdot \cos\varphi$ (Power $P = I \cdot P$-factor)

W-factor $= \sqrt{3} \cdot U_n \cdot \cos\varphi \cdot 1/4$ h (Energy $W = I \cdot W$-factor)

1) The warning is issued if cos φ is between cos φ_v and ½ · (1 + cos φ_v), e.g. for cos $\varphi_v = 0.9$ the warning range is $0.9 \le \cos\varphi \le 0.95$; below this an alarm is issued, meaning also for a capacitive cos φ (cross-hatched area)

Fig. 2/5: **Examples for limit value settings in bar diagrams**

Load curves

Line diagrams with time as the X-coordinate are defined as load curves. Various measured quantities may be plotted on the Y-coordinate. Power-related load curves are called load profiles. Load curves for voltages, currents, active power factors, power factors, and many more can be used for evaluations.

The time period in which these measured values are displayed determines whether yearly, monthly, weekly, or daily load curves are issued (Fig. 2/6). Yearly load curves, for example, allow seasonal effects to be deduced or additional shifts, company holidays, or long-term disconnections of important loads to be detected. Minimal power limits during night-time power curbs and fluctuations in peak power values become apparent. Monthly load curves allow load differences between day and night and the influence of bridge days or bank holidays to be illustrated. For example, Fig. 2/6 illustrates the effect of the bank holiday at the turn of the year in the first calendar week (CW 1) and the reduced power demand during the other workdays of this week. The weekly load curve reveals details of demand peaks and daily load variations. For example, the load curves of Monday and Friday may significantly differ from those for Tuesday, Wednesday, and Thursday if machine rigging (Monday) and stripping times (Friday) or a large proportion of weekend commuters have an influence here. Daily load curves help identify fixed times such as breaks or shift changes. An increased power demand for canteens around break times and midday may also be noticeable.

In turn, different time intervals can be bundled according to typical requirements. For example, workdays or bank holidays could be combined with weekend days in daily load curves. Special constraints, such as the effect of air conditioning on certain days might be a selection criterion for periods under review.

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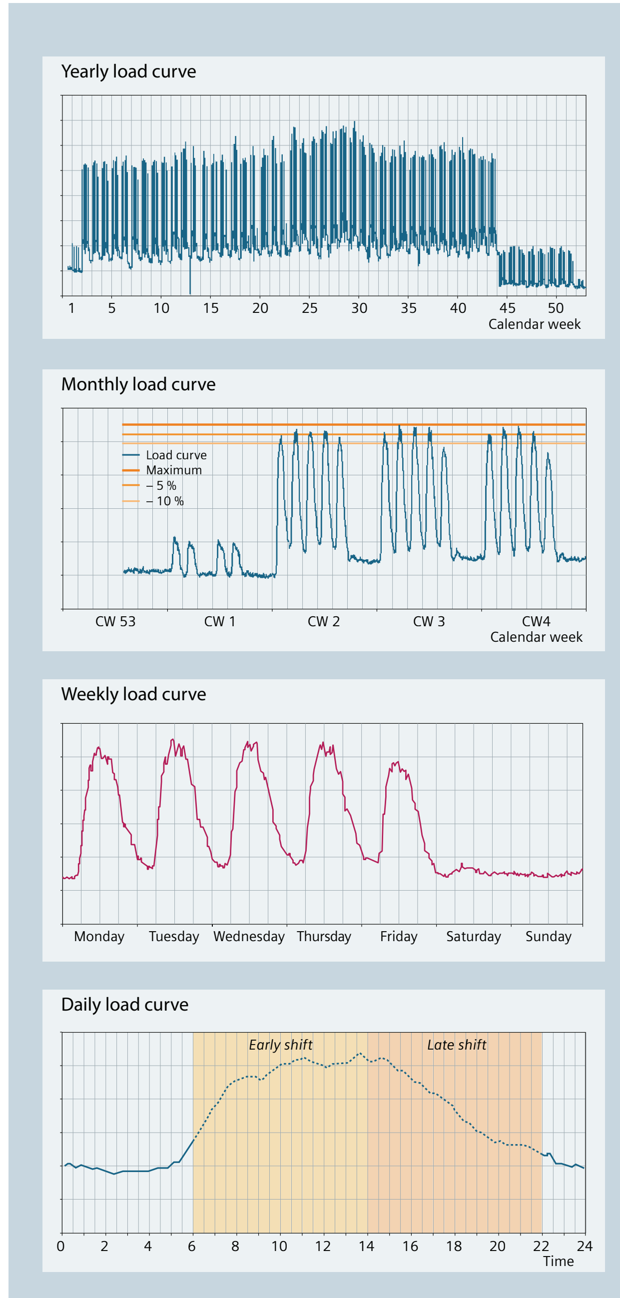

Fig. 2/6: **Examples for evaluations according to load curves**

Profiles

Data interpretation is simplified when line diagrams as an analysis of time-related measured values are combined into distributions or other statistical curve shapes. Typical examples are the frequency distribution for the power demand and the utilization profile (Fig. 2/7). In contrast to the load profile, operating times are plotted on the utilization profile (Fig. 2/7 left) as a function of power. This facilitates evaluations with regard to no-load and transmission losses. In a frequency distribution, power values are plotted over cumulated operating times (Fig. 2/7 right).

This allows, for example, conclusions to be drawn from the dip at high power outputs about the effectiveness of a peak load reduction. Kinks in the distribution, for example, designate the number of shifts and factory closure at the weekends (colour-marked areas in Fig. 2/7 right):
"Sat/Sun" closed on weekends,
"Sun" only closed on one day (Sunday),
1-shift "kink" between 1,500 h and 2,500 h,
2-shift "kink" between 3,000 h and 4,500 h,
3-shift "kink" between 4,500 h and 6,000 h.

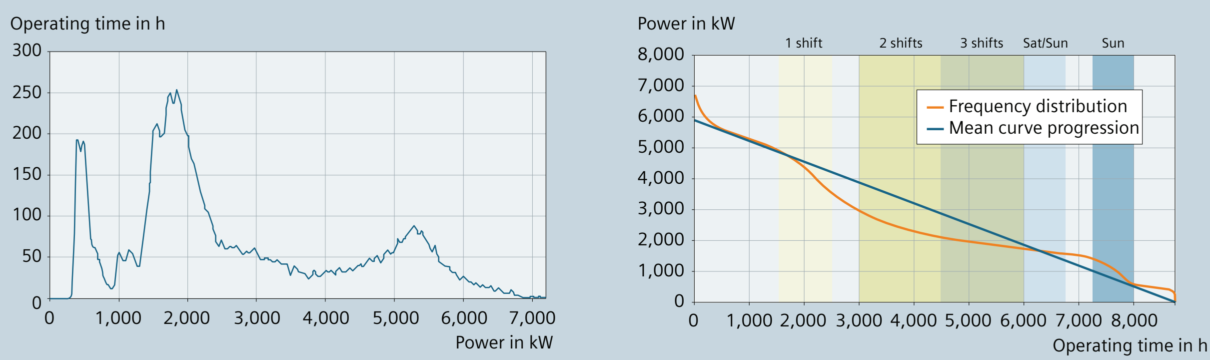

Fig. 2/7: **Utilization profile and power frequency distribution**

Selective evaluations

A graphic illustration of events at certain points in time can enhance analysis options if a suitable data selection and a matching form of representation are chosen. A well-known example is the maxima evaluation. Together with a time-dependent plotting of power peaks (Fig. 2/8) it helps to judge the potential for a load management system and hence for optimization of the demand charge.

15-minutes measured values	Date/time	15-minutes measured values	Date/time
11,792 kW	Tue 25.03.14 09:45	11,328 kW	Thur 20.03.14 13:15
11,696 kW	Wed 05.03.14 11:45	11,296 kW	Thur 20.03.14 13:00
11,648 kW	Wed 26.03.14 10:00	11,280 kW	Wed 19.03.14 11:30
11,632 kW	Wed 05.03.14 11:15	11,248 kW	Wed 05.03.14 11:30
11,632 kW	Thur 20.03.14 12:00	11,216 kW	Wed 26.03.14 06:30
11,568 kW	Wed 26.03.14 21:15	11,200 kW	Tue 04.03.14 10:45
11,488 kW	Thur 20.03.14 12:30	11,200 kW	Wed 26.03.14 20:45
11,472 kW	Thur 20.03.14 12:45	11,184 kW	Wed 26.03.14 20:30
11,440 kW	Thur 20.03.14 12:15	11,168 kW	Tue 11.03.14 15:00
11,424 kW	Tue 25.03.14 09:15	11,168 kW	Wed 19.03.14 11:15
11,424 kW	Tue 25.03.14 09:30	11,104 kW	Wed 26.03.14 02:00
11,408 kW	Thur 06.03.14 03:00	11,088 kW	Wed 05.03.14 16:00
11,360 kW	Wed 19.03.14 11:45	11,072 kW	Wed 19.03.14 12:45
11,344 kW	Wed 05.03.14 12:00	11,072 kW	Wed 19.03.14 13:00
11,328 kW	Wed 19.03.14 12:30	11.072 kW	Wed 19.03.14 13:15
Monthly maximum	11,792 kW		
Peak reduction by 5 %	11,202 kW	**Difference from maximum to 30th measured value**	720 kW
by 10 %	10,613 kW		6.11 %

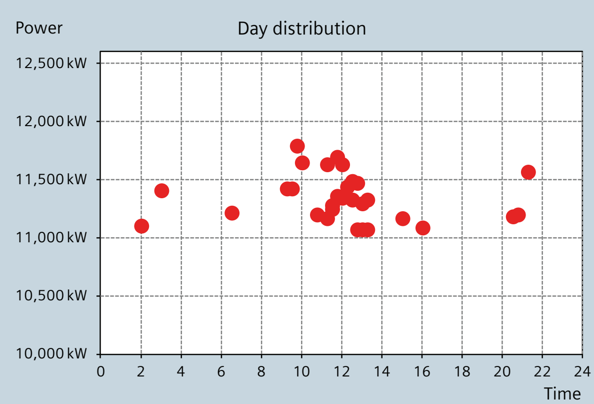

Fig. 2/8: **Maxima evaluation**

Characteristic values

Characteristic values such as the mean and maximum values of power provide an overview in tabular form of some "Key Performance Indicators" (KPI) or "Energy Performance Indicators" (EnPI). Periodic and continuous compilation of this data is a prerequisite for energy management as complying with ISO 50001. These characteristic values may be graphically shown as bar or pie charts.

Typical characteristic values are:
- Power as maximum, mean (arithmetic mean), and minimum value
- Energy, both absolute and cumulated
- Operating time (use period), as the quotient of electricity consumption and maximum purchased power (as absolute value in relation to the respective month and the year, as well as relative value in percent, each split into a uniform time period, for example 31 days per month)
- Evaluations such as the share of base load or peak load, if such a billing method has been agreed in electricity purchase contracts

The compilation of a bar chart for the electricity consumption and a point-to-point diagram for the maximum power values during a month reflects the operating time (use period) for the periods under review (Fig. 2/9).

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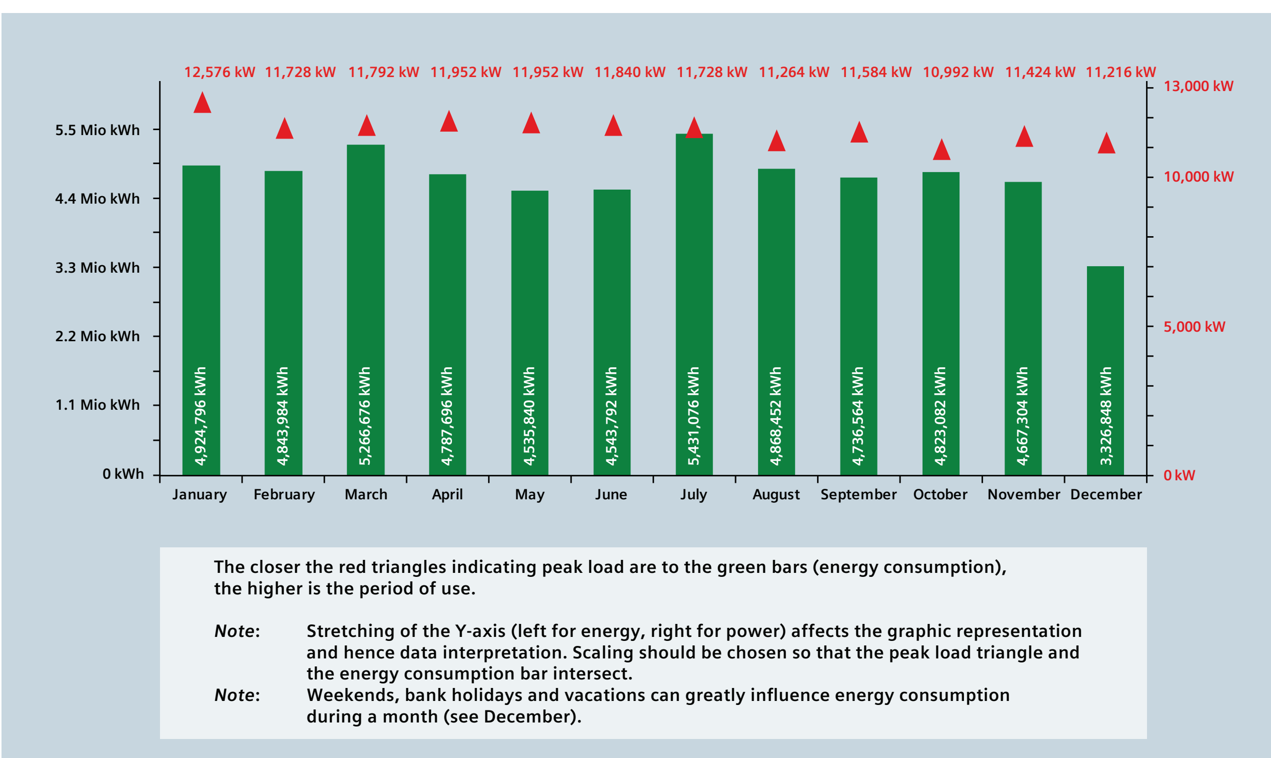


Fig. 2/9: **Electricity consumption and power peaks for 12 months a year**

2.5 Planning and forecasting

Planning and forecasting are important prerequisites for energy purchasing. The liberalization of the electricity market has produced highly volatile market prices. These prices in turn affect consumer behaviour, their planning and forecasts regarding investment and operating costs. Operating costs are linked to energy consumption and hence energy transparency becomes increasingly important. Energy transparency allows an energy management system (EnMS) to be built up in compliance with ISO 50001. Planning and forecasts in the EnMs characterize the transition from the measuring data and analysis of the past and present towards future prospects and the action entailed (this is the "Do" in the process cycle of ISO 50001: PDCA cycle / Plan - Do - Check - Act; see [2.2].

The load profiles compiled from the measurement data over a certain period of time, such as a year, are statistically analysed and linked to create the "synthetic load profiles" (Fig. 2/10). These synthetic load profiles are used to create demand forecasts with due consideration given to empirical values and intended modes of operation.

Estimations of maximum operating currents as needed in designing the appliances usually produce unrealistic maximum values for the energy cost, as if the assumption was one of a permanent operation under maximum power. Hoverer, as load profiles for a real power demand are usually not known in the planning phases, the only way is to use a theoretically established trend of the time-dependent power demand and resulting energy consumption.

Synthetic load profiles are created as averaged curves for cyclically repetitive time sequences. Typical averaged curves for the power or electricity demand shall preferably be effective demand estimations and should therefore be based on the closest possible approximation of the anticipated consumption pattern during system operation.

Fig. 2/10 distinguishes between an absolute and a relative scaling. The absolute scale identifies the physical values, for example for power or energy. On the "relative" scale, the data refers to the mean value of the respective measured quantity. The peak value in Fig. 2/10 represents the highest assumed quarter-hour value drawn on for dimensioning the electric power distribution system.

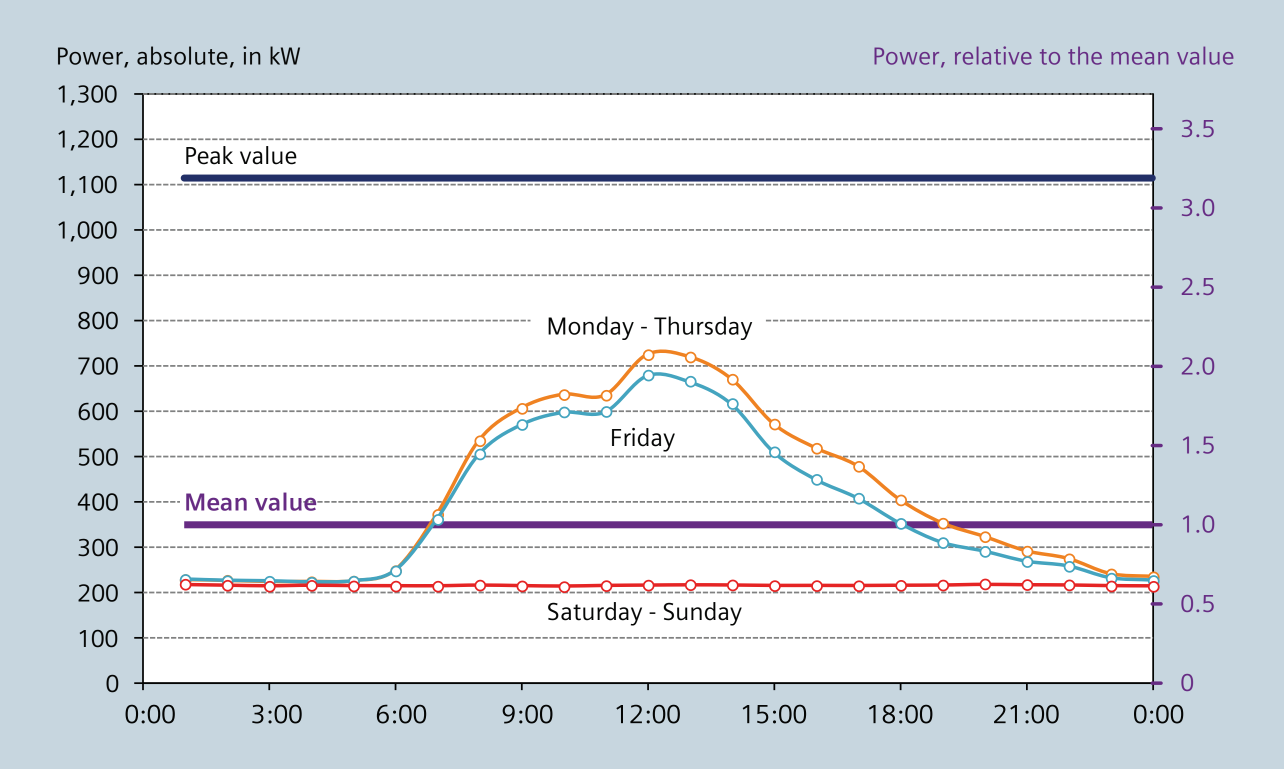


Fig. 2/10: **Synthetic load profiles - characteristic for an office building**

Note: The peak value of a synthetic load profile needn't be a measured value. On the basis of future development assumptions (e.g. use of a load management system), a "synthetic peak value" may also be entered here. As a rule, the peak value does not correspond to the maximum value of a synthetic load profile. After all, for a synthetic load profile numerous values are averaged for the individual times.

In synthetic load profiles, we expect that buildings and technical installations which are used in a comparable manner behave in the same way. However, differences in the general setting (amenities, user behaviour, environment) may result in different curve shapes, different absolute means and deviating peak values. Fig. 2/11 compares two different types of office buildings.

Three factors are especially significant for the identification of synthetic load profiles and their importance for energy transparency:

- Curve progression:
  e.g. as assessment basis for load management and forecast
- Power mean for the "absolute" curve:
  e. g. when judging to what extent power consumption can be influenced
- Peak factor (load factor):
  the quotient from power peak and power mean characterizes the annual operating time (use period); electricity consumption is the product of power peak and annual operating time

In order to dimension protection devices in the electric power distribution system, the maximum power demand must be factored in. This demand corresponds to the product of power mean value and peak factor. Often, safety margins are also factored in to cover special cases and possible particularities. Annex 8.1 provides bibliographical data for the power demand, power consumption, and annual operating time for different office buildings. This is to clearly illustrate the issue of an abundance of framework parameters and numerous variation options.

Note: The peak factor for the air-conditioned office building is lower in Fig. 2/11 than for the naturally ventilated office building. However, the power mean value standardized to factor "1" will be much higher as an absolute value owing to the power demand of the air conditioning system.

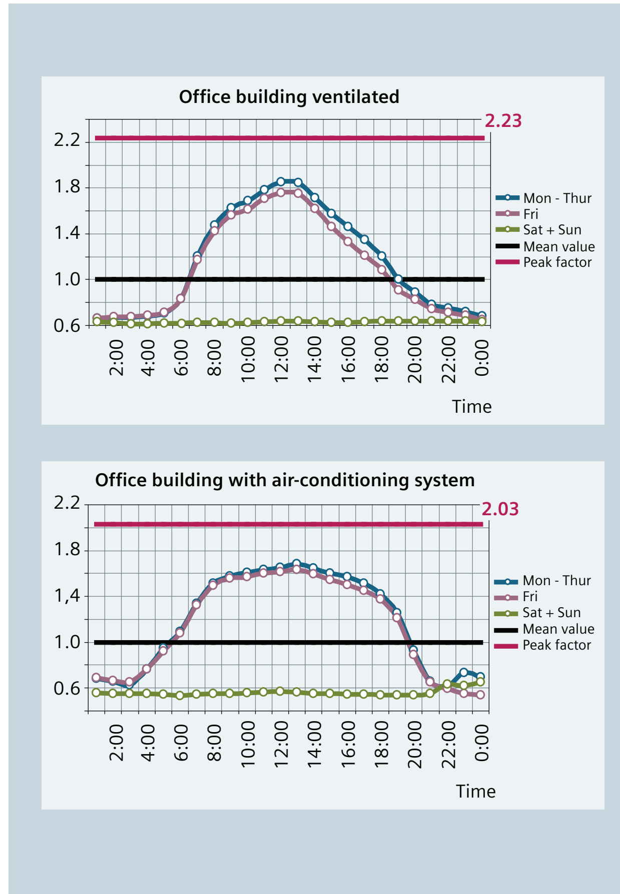


Fig. 2/11: **Different synthetic load profiles for the same building type: top showing an office building with natural ventilation through windows and environment; bottom for a fully air-conditioned office building**

Chapter 3

Measured value acquisition in the distribution grid and its importance in the electricity market

3 Measured value acquisition in the distribution grid and its importance in the electricity market

To obtain energy transparency within the distribution grid, measured values are acquired at three levels, namely
• Supply,
• Distribution, and
• Application.

At the supply, that is the point of supply to the customer, the electricity purchased ("imported"), and/or the energy fed back into the distribution grid are measured. In order to verify the data submitted to the customer by the metering operator and to obtain more comprehensive information, the customer may perform additional check measurements (Fig. 3/1).

Costs are established on the basis of the measured values provided by the metering operator. The total cost is composed of the cost components listed in Tab. 3/1. The power consumer himself determines power consumption, the power purchased and the scope of data to be provided by the metering operator.

3

The quarter-hour active energy values measured are used as source data for the import from the distribution grid. As kilowatt per hour rate, a permissible value range for the active power factor (usually $\cos \varphi \geq 0.9$ inductive) is agreed on. If this range is exceeded, the metering operator specifies the entire reactive energy of the respective quarter-hour intervals, so that they can be billed via the agreed kilowatt per hour rate for reactive energy.

For the purpose of energy feed-back, the metering operator also supplies the corresponding active energy values. If the agreed active power factor range is exceeded, the following applies in the same way: the entire reactive energy of the respective quarter-hour interval can be billed.

The metering operator only offers the quarter-hourly measured energy values as a sum over all three phases. These values can be provided at the end of a quarter-hour at the earliest. Customers with a load curve meter are supplied with these values on the following day at the earliest.

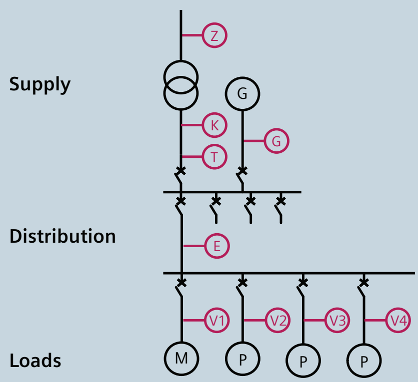
If customers are interested in up-to-date measured values and characteristic parameters and if they wish to analyse more than just energy data, they must install an appliance capable of performing check measurements (Fig. 3/1). Measurement instruments featuring a power system analysis function are suitable for this purpose. Besides data acquisition of the cumulative energy over all three phases, they provide energy values per phase as active power and reactive power component for energy import and backfeed, corresponding power values, active power factors, power factors, harmonic contents of voltage (THD_U), and current (THD_I) and are also capable of detecting flicker etc. (see chap. 2), dependent on the device chosen (Tab. 3/2).

For cost reasons, the device for check measurements is normally installed in the low-voltage circuit. In case of voltage supply into the medium-voltage power system, the impact of the transformer and the cabling must be taken into account when check measurements at low-voltage level are compared to measurements provided by the metering operator at the point of supply. If the customer operates his own medium-voltage power system downstream of the supply received by the distribution grid operator, this check measurement may, of course, be taken at the customer's medium-voltage level circuit downstream of the supply point meter.

In addition to the supply-side check measurement, further metering locations should be provided in the customer's distribution system in order to obtain more detailed information and thus create energy transparency. Fig. 3/1 and Tab. 3/2 show measured value acquisition for typical components of distribution system levels downstream of the point of supply.

Electricity market participant	Cost type	Service rendered
Grid operator	Demand charge (composed of costs for connection to grid plus grid use)	Provision of the grid infrastructure (performance-dependent) and balancing of grid losses (energy-dependent)
Metering operator	Costs for metering location(s) and data provision	Supply point meter and data analysis
Electricity supplier	Energy cost	Energy supply (Kilowatt per hour rates for active and reactive energy)
Government, local communities	Taxes, duties and levies	Administration, community and public infrastructure, energy and economic policy

Tab. 3/1: **Electricity cost components and related market participants**



- (Z) Supply point meter
- (K) Check measurement
- (T) Transformer feeder
- (G) Generator feeder
- (E) Power distribution
- (V1) Load - 3-phase, linear symmetrical, e.g. motor
- (V2) Load - linear and asymmetrical, e.g. floor distribution board
- (V3) Load - non-linear and asymmetrical, e.g. electronic switching device
- (V4) Load - cost centre allocation, energy billing

Fig. 3/1: **Measured values and characteristic parameters at the various distribution levels**

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Measured quantities / characteristic parameters		Active energy Import	Active energy Backfeed	Reactive energy Import	Reactive energy Backfeed	Apparent energy sum	Apparent power per phase	Apparent power sum	Active power per phase	Reactive power sum	Reactive power per phase	Voltage phase-phase	Voltage phase-neutral	Phase current	Neutral current	Active power factor sum	Active power factor per phase	Power factors	Harmonics per phase current	Harmonics per phase-to-phase voltage
Formula symbols		$\overrightarrow{W}$	$\overleftarrow{W}$	$\overrightarrow{W}_Q$	$\overleftarrow{W}_Q$	S_Σ	S_{L1}, S_{L2}, S_{L3}	P_Σ	P_{L1}, P_{L2}, P_{L3}	Q_Σ	Q_{L1}, Q_{L2}, Q_{L3}	$U_{L1\text{-}L2}$, $U_{L2\text{-}L3}$, $U_{L3\text{-}L1}$	$U_{L1\text{-}N}$, $U_{L2\text{-}N}$, $U_{L3\text{-}N}$	I_{L1}, I_{L2}, I_{L3}	I_N	$\cos\varphi_\Sigma$	$\cos\varphi_{L1}$, $\cos\varphi_{L2}$, $\cos\varphi_{L3}$	λ_{L1}, λ_{L2}, λ_{L3}	THD_{IL1}, THD_{IL2}, THD_{IL3}	$THD_{UL1\text{-}L2}$, $THD_{UL2\text{-}L3}$, $THD_{UL3\text{-}L1}$
Units		kWh	kWh	kvarh	kvarh	kVA	kVA	kW	kW	kvar	kvar	V	V	A	A				%	%
Measured values of metering operator	Z	●	● [1]	● [1]	● [1]															
Check measurement	K	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Transformer feeder	T													●	●		●	●	●	
Generator feeder	G	●												●	●		●			
Energy distribution	E													●	●					
Load, symmetric linear	V1								●					●	●	●				
Load, asymmetric linear	V2								●	●				●	●		●	●		
Load, asymmetric non-linear	V3								●	●				●	●		●	●	●	
Load – cost centre allocation, energy billing	V4	●		● [1]										●	●					

[1] optional measurement

Tab. 3/2: **Measured values and characteristic parameters at various locations in the customer's power system**

3.1 Measured quantities and characteristic parameters in the customer's power system

Besides the parameters described before in the context of the check measurement, neutral currents and phase-specific power factors may also be of interest. Neutral currents are generated by an uneven load of the three phases and by harmonics produced by power consuming equipment.

Harmonics also make the difference between power factor λ and active power factor cos φ. The active power factor cos φ is the ratio of active current to apparent current at the fundamental frequency of 50 Hz. Whereas the power factor λ also factors in the harmonic components in the active and apparent current.

Active power factor $\cos\varphi = \frac{P}{S}$

Power factor $\lambda = \frac{\cos\varphi}{\sqrt{1 + THD_I^2}}$

3

The THD value identifies the percentage of the sum of all harmonic components of a parameter relative to the value of the fundamental. Dependent on the metering location and the equipment characteristic, it may be appropriate to display and compile different measured quantities and parameters (Tab. 3/2).

Many parameters can be derived from measured values with the aid of the formulas given in Fig. 3/2. The following also holds good:

$$P_{\text{Phase}} = W_{\text{Phase}} \cdot 4\,\text{h}^{-1} \text{ (referred to quarter-hour)}$$

$$S_{\text{Phase}} = \frac{P_{\text{Phase}}}{\cos\varphi_{\text{Phase}}} \quad \text{(without harmonics)}$$

$$S_{\text{Phase}} = \frac{P_{\text{Phase}}}{\lambda_{\text{Phase}}} \quad \text{(with harmonics)}$$

$$I_{\text{Phase}} = \frac{S_{\text{Phase}}}{U} = \frac{S_{\text{Phase}}}{400\,\text{V}/\sqrt{3}}$$

$$|S_N| = |\vec{S}_{L1} + \vec{S}_{L2} + \vec{S}_{L3}| \quad \text{(see fig. 3/3)}$$

$$I_N = \frac{S_N}{U}$$

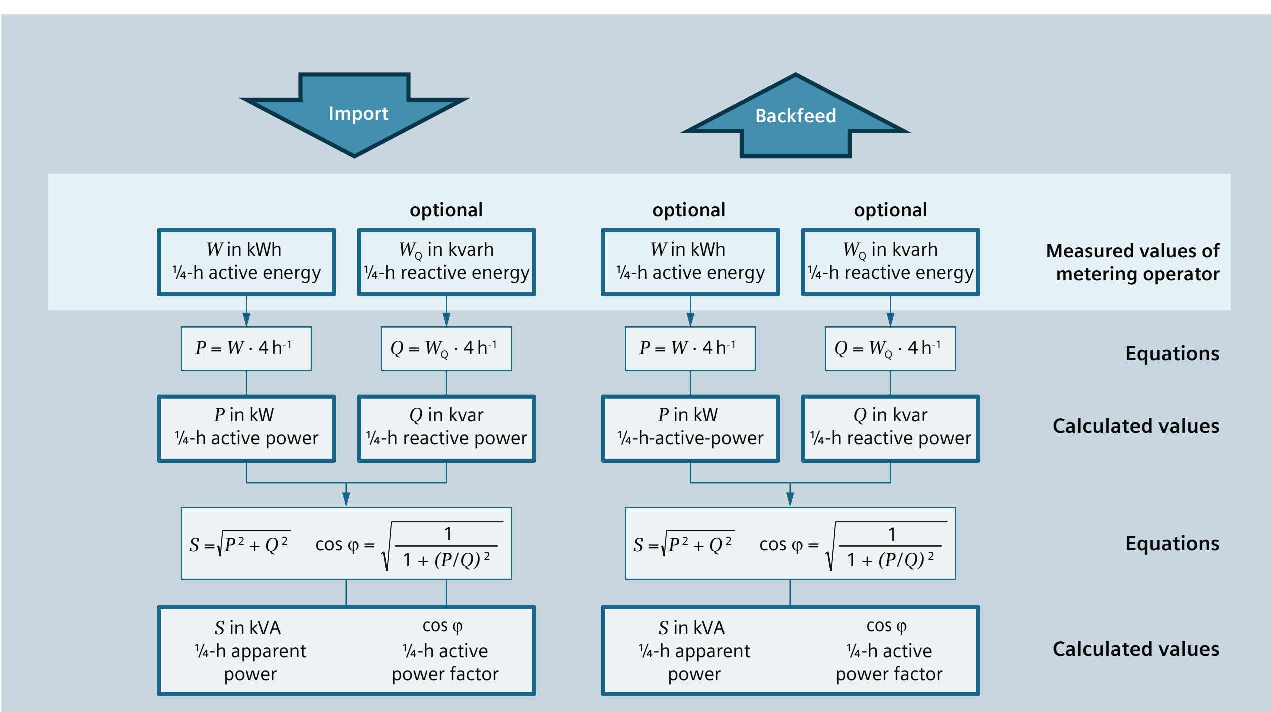


Fig. 3/2: **Interrelation between energy and power values**

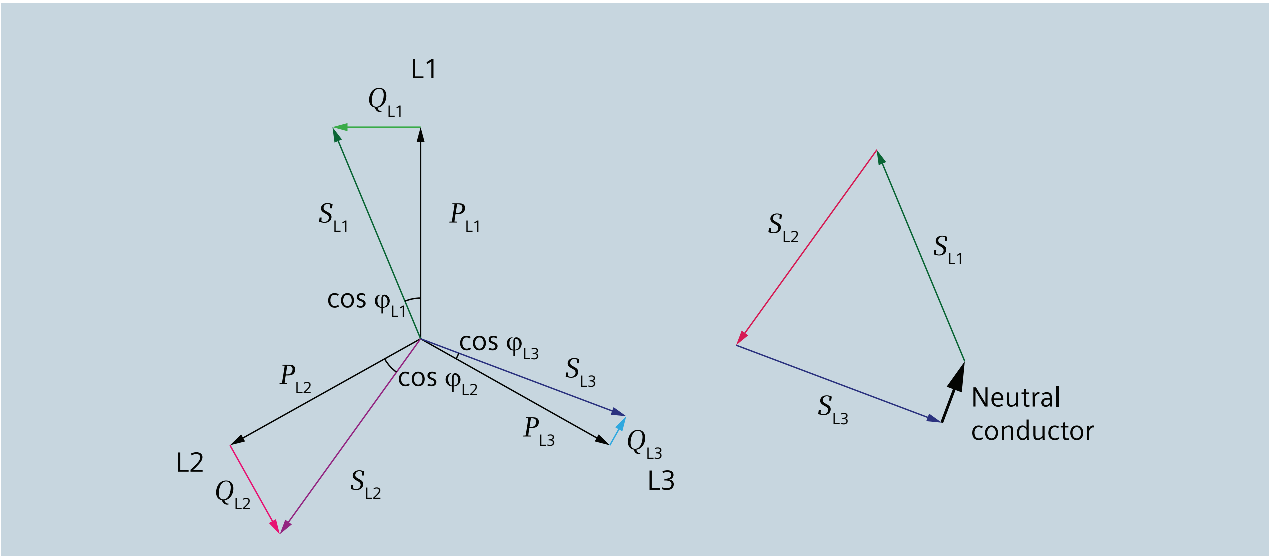
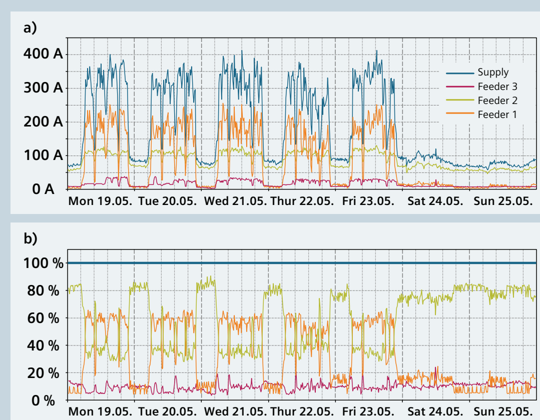


Fig. 3/3: **Vectorial determination of the neutral conductor's apparent power**

Data can be employed for:

- Phase currents:
  Determining reserves by comparison with the maximum permissible currents in the branch circuit (set values of the overload protection device, fuse dimensioning)
- Active power factor:
  Estimating the amount of reactive power required and thus a criterion for the necessity of a compensation system
- THD_I , THD_U values:
  High harmonic currents may cause trouble on generators and UPS installations being used
- Load profile of the active energy (summated value)
  Describes the customer's demand, shows load peaks as well as a day-specific consumption pattern which may be utilized for an energy management system (ISO 50001)

Additional information is gained by comparing measured values and characteristic parameters at different locations in the power distribution system. A typical example is one of recording the utilization of individual outgoing feeders and comparing these values in relation to incoming feeders. In the case of extensions or structural changes being made in the distribution, such information can be utilized for a more advantageous re-distribution or load re-assignments to the various outgoing feeders (Fig. 3/4).



Feeder 3:
Apparently, only small loads are connected;
Relations between daytime and night-time operation as well as weekend and weekday operation correspond to supply

Feeder 2:
Demand for night-time operation and weekends nearly corresponds to the full power quantity supplied; possibly for safety equipment

Feeder 1:
Daytime use; noticeable are the three power dips at around 10 a. m., 2 p. m., and 6 p. m. (early shift break – shift change – late shift break)

Fig. 3/4: **Example for outgoing feeder currents and their associated supply current in the distribution system;**
a) absolute values and
b) relative values compared to the supply current (= 100 %)

3.2 Derivation from synthetic load curves

The graphic comparison of individual day curves in the absolute or relative value curve (Fig. 3/5) can be used as a pre-stage for creating synthetic load curves. In the absolute value representation, day curves are averaged and plotted together with the day curves for maxima and minima. In the relative value representation, the relative deviations of the individual measured values (e.g. 15-minutes power values) are plotted as percentages for the different weekdays as against to the mean value (equals 100 %). Temporally limited uses within the building, such as canteens or shift work, allow effects on the peak load management (consideration of peak values in the absolute value representation in Fig. 3/5) and on the adherence to forecasts submitted (deviations in the relative value representation in Fig. 3/5) to be detected. This helps to better estimate the cost-benefit ratio for load management.

By a further averaging to whole hours, the quarter-hour means from the absolute value representation can be utilized as synthetic load curves for forecasting and a future-oriented load control. In order to keep the influence of singular events and external factors such as weather and season as low as possible, comparable daily load curves of at least a whole year should be employed for synthesizing load profiles. Conversely, it is sometimes possible to gain adjustment parameters for systematic influencing factors (temperature dependency, influence of cloud formation, influence of the number of staff members, number of people in a room, ...) from comparisons between the synthetic load curve with the specific daily load curves (for example by way of a relative value representation). These factors may then be used for improving the forecast quality.

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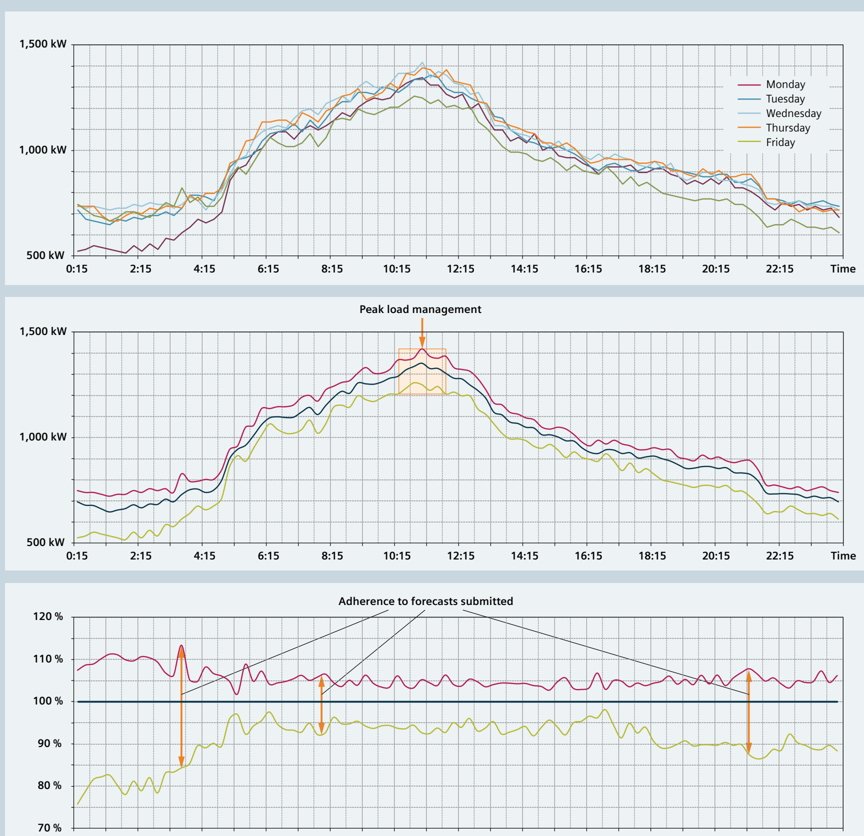


Fig. 3/5: **Daily load curve for workdays (Monday – Friday) as well as absolute and relative value representation for minima and maxima with interesting analysis times for peak load management and adherence to forecasts submitted being marked in orange**

3.3 Forecasts and the electricity market

The importance of consumption forecasts is going to increase. Whereas smart meters have previously been installed upwards of an annual energy consumption above 100,000 kWh/a, such meters will in future be mounted upwards of an electricity consumption of more than 60,000 kWh/a. With the data the electricity supplier receives from the metering operator, he is able to assess consumer behaviour. Since the electricity supplier must back his electricity purchase by forecasts, he will be charged for additional costs in case of deviations from the forecast. He will forward these additional costs - based on the data received - to his customers who do not adhere to their forecasts.

For periods of more than a week, long-term forecasts are created. Correspondingly, electricity suppliers cover their demand by directly buying from power station operators and/or from the electricity exchange. Energy forecasts for the following week (usually on a Thursday covering the seven days of the following week) result in fairly accurate load profiles. Weather forecasts for calculating wind power and solar energy also go into these forecasts. These weather forecasts are provided by specialized companies with a prediction accuracy of more than 90%.

Deviations as occurring during operations from the long-term and the weekly forecast are offset as much as possible by purchase and sale through the electricity exchange. In order to take account of short-term changes, the adjustment between weekly and daily forecast is performed every day. Here too, differences are offset through the exchange ("day-ahead trade"). The smallest unit of a target-actual adjustment is a quarter-hour within the subsequent hour. These difference quantities are traded in the "intraday trade" at the electricity exchange (see chap. 1 and [3.1]).

For the consumer it is a matter of adapting every quarter-hour demand as closely to the forecast submitted as possible (see Fig. 1/3). Extra consumption must often be dearly bought, since the electricity supplier must order this additional quantity through a balancing reserve. Conversely, less consumption may not result in a cost reduction for the consumer.

Aggregation into an overall forecast

For submitting an overall forecast to the electricity supplier, the energetic behaviour of the building together with its various applications and production facilities and their interrelations must be known. An important prerequisite for forecasting is the planning capability as facilitated, for example, by automation technology integrated in production plants. Control access of the Manufacturing Execution System (MES) allows processes in the automation system to be controlled. Production planning defines the individual process steps and associated time sequences and the MES controls the corresponding automated sequences (Fig. 3/6). For active planning of electric energy demand, the typical load curve data for individual process steps must be stored in the automation system. An appropriate aggregation of load curves allows the manufacturing execution system to then optimize the energy demand for the production flow with due consideration given to the production targets.

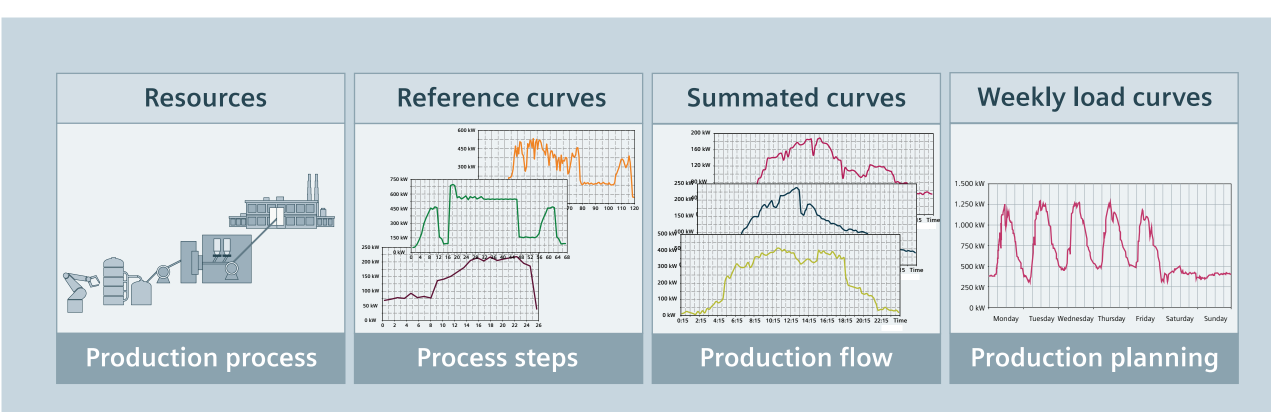


Fig. 3/6: **Aggregation into an overall forecast**

3

3

Controlling and switching

To level out deviations from submitted forecasts, loads can be connected into or disconnected from supply and can be curbed or increased by means of a load management system (Fig. 3/7). Innumerable switching and control strategies dependent on the respective applications and targets can often be applied.

A priority list containing switching and control data about the various loads is a good aid for creating and implementing suitable strategies. This list includes data of when and how which load, power generator, or energy storage device and which switch, regulator, or control device can be applied (keyword: "characteristics"). For the controllable loads this also means defining the control range and their response time. Switching devices for load management must be chosen according to product-specific operating cycles and the profiles to be expected. Load management flexibility is characterized by an overlay and link-up of response options which in keeping with the given conditions are feasible at certain points in time and under the usage targets set.

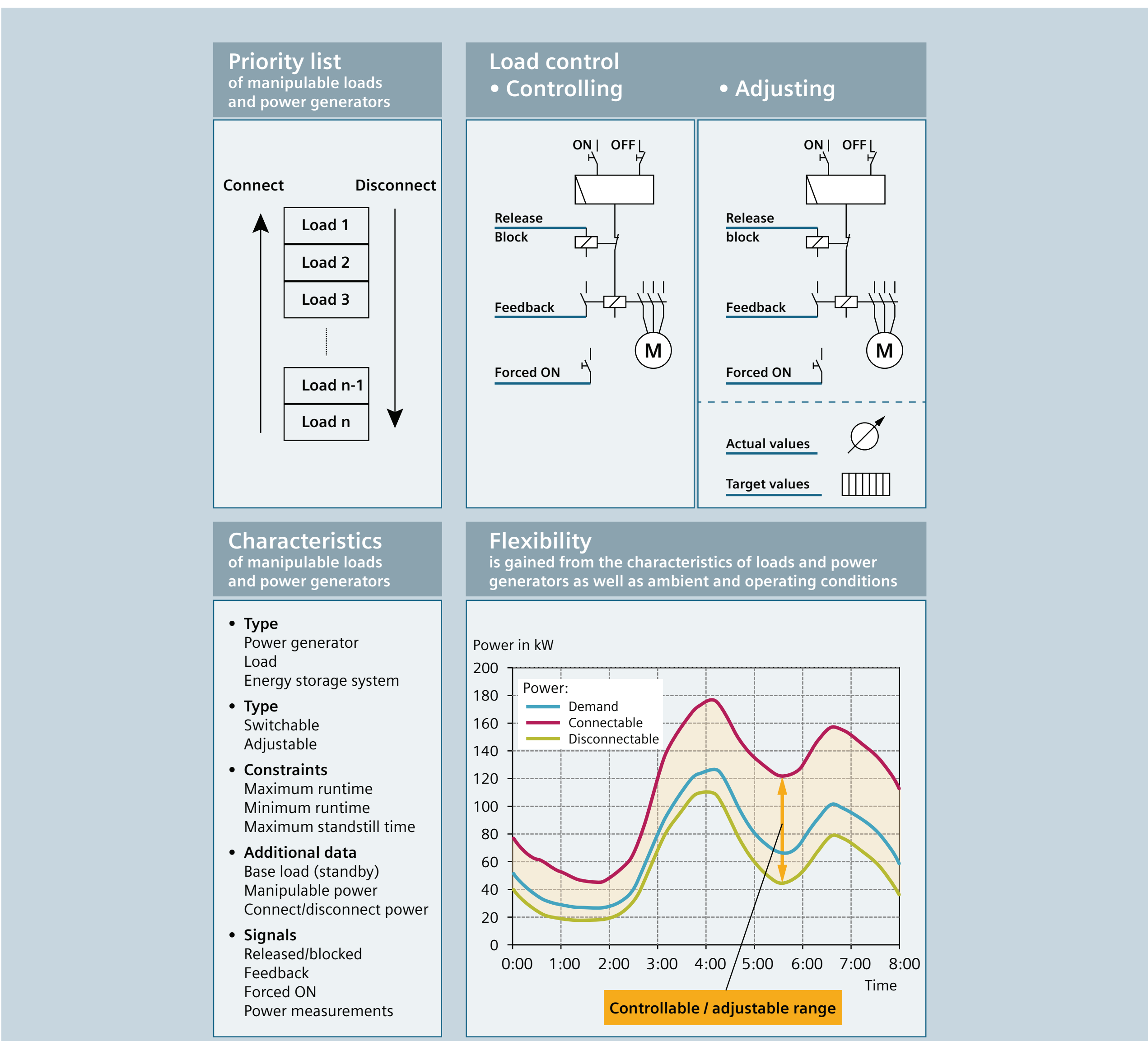


Fig. 3/7: **Consumption adjustment using strategical load management**

The prosumer

When the customer combines his own power generation, for example from renewable power sources and combined heat and power generating plants with his own consumption and power supply from the supply grid (Fig. 3/8), planning should make provisions to integrate and link as many framework parameters for load management as possible:

- Synthetic load curves for the customer's own demand
- Power output forecast for a photovoltaic system linked to the weather data for solar radiation
- Power output linked to the heat demand over time for a heat-controlled CHP plant

In addition, ongoing changes in production planning and in process steps ranging up to start and stop conditions for machinery and production lines must be taken into account. Similarly, staff deployment options and further operational and servicing conditions can be employed to draw up a reliable consumption schedule. Energy transparency and the derivable relations and forecasts are important for a "prosumer" (who is simultaneously a producer and consumer of energy) to optimize his forecasting effectiveness or to utilize the existing flexibility to his benefit.

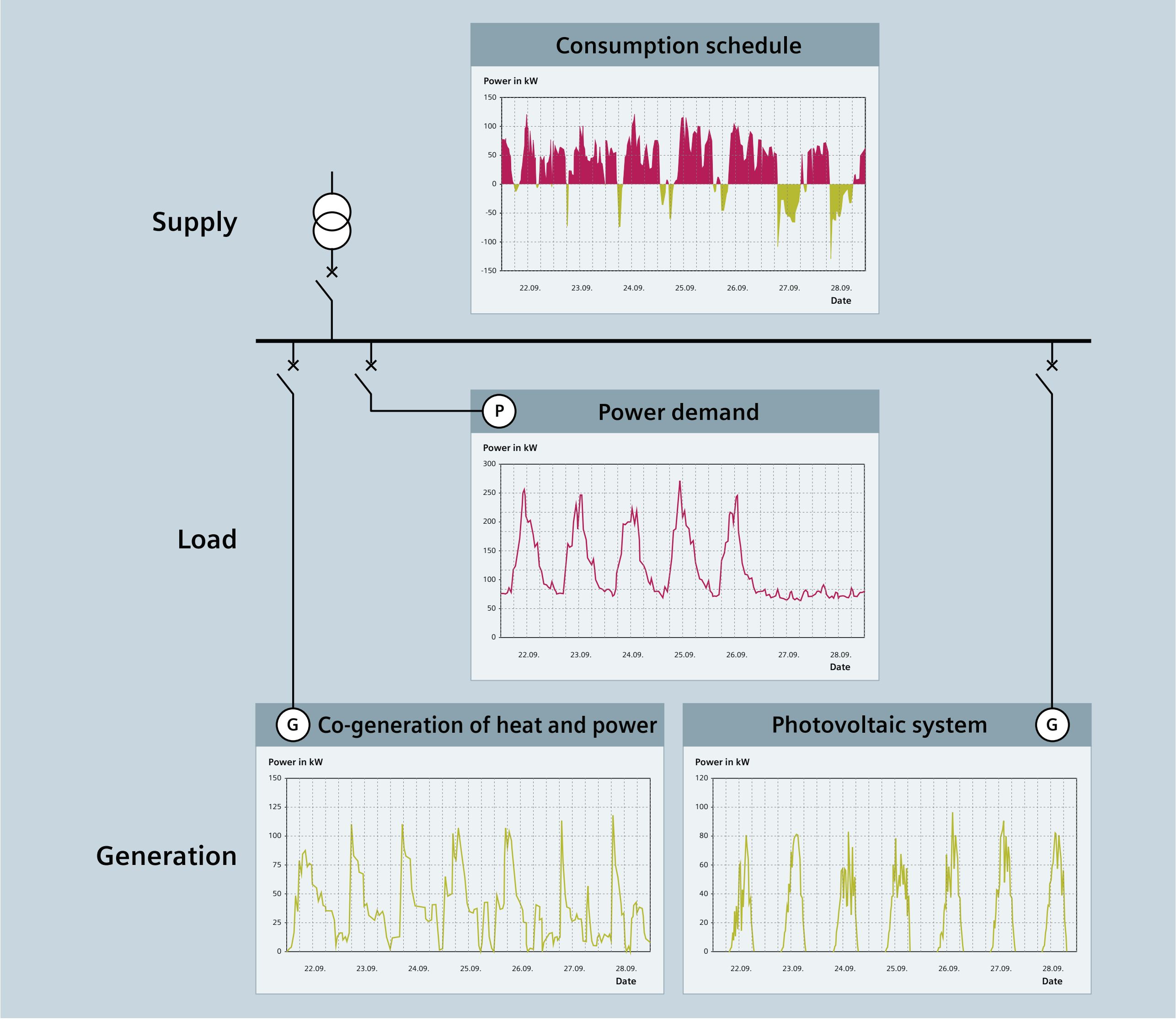


Fig. 3/8: **Combination of power consumption and generation**

Electricity market

In Germany, the increase of power generated on the electricity customer's own premises or plant goes hand in hand with the restructuring of the electricity market ("Electricity Market 2.0" see draft for an Electricity Market Act [3.2]). A possible consequence of this is an increasing demand for power stations enabling load controlling and peak load power stations as well as a rising demand for flexibility in consumption behaviour or for storage possibilities. At the same time, the expectation is for electricity trading to be performed efficiently through various sub-markets (Electricity Exchange as well as extra-exchange "over the counter"), see White Paper [3.3]. This means employing prices on the electricity and power market to control electricity generation and consumption.

Incentives for balancing group loyalty are being enhanced. Any deviation from it should be settled according to the "user pays" principle through the expensive balancing energy system with the balancing group manager. Access to the secondary balancing power market will be facilitated for service providers in the load management sector [3.2].

3

In particular, remote-controlled power reductions or disconnections of power generating sets may be part of the action plan of grid operators (negative balancing power in Fig. 3/9). In Germany, the Renewable Energies Act (EEG 2017) [3.2] and [3.4] and the Combined Heat and Power Act (KWK-G) [3.5] govern the requirements of power control and power metering by the grid operator conditional upon the power supplied (>100 kW) by renewable power generation and combined heat and power plants.

According to EEG and KWK-G there is an obligation on the part of the grid operator to connect renewable power generation plants and highly efficient combined heat and power plants to the grid. This is to enable trading of the electricity fed in. The different acceptance obligations and remunerations including premium or surcharge payments can be found in the current publications of the two acts. Current prices for electricity supplied from CHP plants can be found on the web pages of the Leipzig EEX, referred to as "KWK Index". Fig. 3/9 provides a basic overview of of the participants and the trading relations in the liberalized electricity market, as described in more detail in the White Paper [3.3].

Energy transparency of one's own generation, storage and electricity consumption will become increasingly important for participation in the electricity market 2.0. The "consumption schedule" will turn into an overall schedule, as delivery shares may appear in addition to consumption shares (see Fig. 3/8). The prosumer will be able to market his flexibility. Usually, however, an improvement of his adherence to forecasts will be his main concern. Alternatively, he may be able to use his flexibility to improve balancing group loyalty or to act through traders on the energy or power market (see White Paper [3.3]). In addition, he can exploit the transparency of power quality, which is crucial for critical loads, for his own benefit.

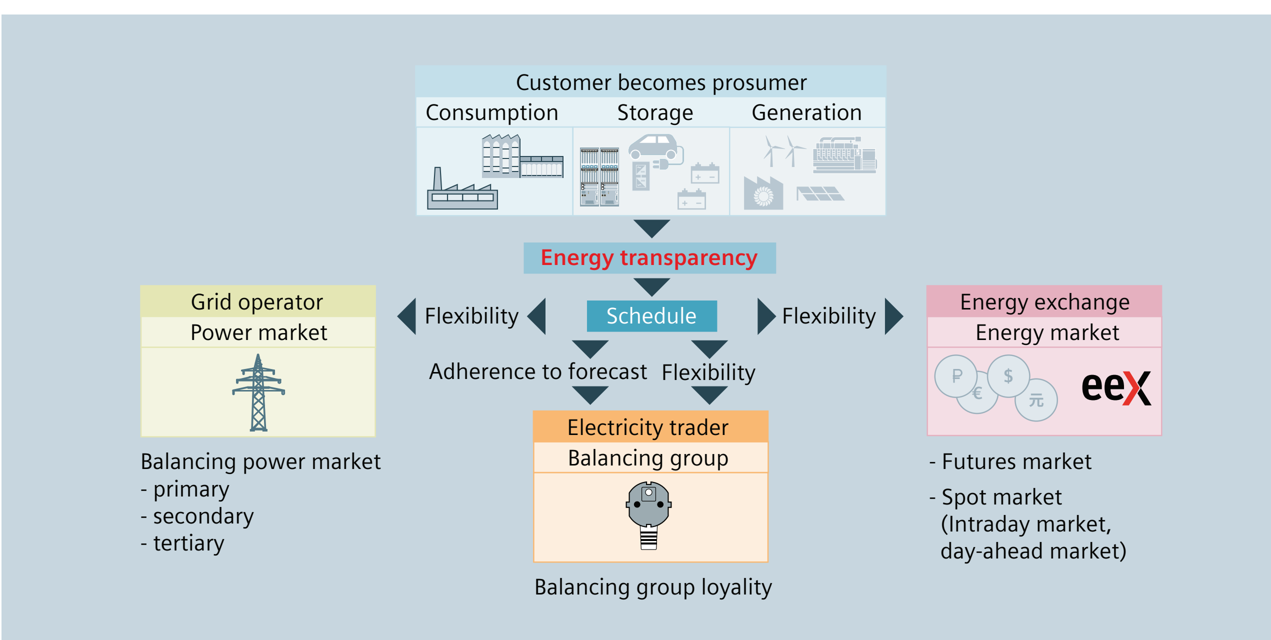


Fig. 3/9: **Roles within the liberalized energy market schematized for grid operation and electricity trading**

Chapter 4

Operational performance and efficiency in electric power distribution

4 Operational performance and efficiency in electric power distribution

Energy distribution and consumer energy use generate losses which are an operating cost factor; this is something the consumer would prefer to have minimized. Motors and drives as power consuming equipment contribute substantially to power losses; this is also true for transformers and generators in the power distribution system.

The most important parameter of an item of equipment is its efficiency. Efficiency η is defined as a quotient of
usable energy and
supplied energy (= output energy + loss energy) as well as
usable power and
supplied power (= usable power + power loss), respectively, and is usually given as a percentage. The total efficiency η of a whole installation or system is the product of the individual degrees of efficiency.

$$\eta_{total} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \ldots$$

The efficiency can depend on operational and ambient conditions. However, it is often sufficient just to consider the degree of loading, since ambient influences such as operating temperature and heat dissipation are low under normal operating conditions. Measurements of power and energy upstream and downstream of an item of equipment allow the degree of efficiency under given operational conditions to be established.

4

4.1 Operating performance of transformers

The effects of harmonics and a parallel operation of transformers will not be considered in this section. In this respect we would refer the reader to the "Technical Series" on the web pages of Siemens TIP Consultant Support (www.siemens.com/tip-cs) and to the support rendered by our Siemens consultants. For the theoretical determination of transformer losses, Siemens specifies the no-load and short-circuit losses of the transformers included in the product range. Total loss as a function of operational apparent power is calculated as follows:

$$P_V = P_0 + (S_{load} / S_r)^2 \cdot P_k$$

with
P_V Transformer power loss
P_0 No-load loss of transformer
P_k Short-circuit loss of transformer
S_{load} Demand of apparent power during operation
S_r Rated apparent power of transformer

The Siemens eco transformers comply with Regulation No. 548/2014 issued by the EU Commission (and thus with the IEC 60076-20 and VDE 0532-76-20 standard). With an efficiency of 99 % and more, they meet the highest EEPL4 requirement (EEPL = energy efficiency performance level) in accordance with IEC 60364-8-1 (VDE 0100-801) in most cases (only our latest GEAFOL eco transformers with an apparent power rating below 250 kVA have a 98.5 % to 99 % efficiency).

As it can be seen from the load curves in Fig. 4/1, the power demand often varies considerably in normal operation. Therefore, a comparison of the utilization profile with the transformer efficiency curves (Fig. 4/1) helps to roughly estimate which transformer type might have the least losses in the given operating conditions. More precise information about the performance of different transformer types can only be gained by a comparison of the loss values calculated from the utilization profile, as required in IEC 60364-8-1 (VDE 0100-801). In most cases all you need to do is examine those transformers more closely whose average load is within the ± 20 % interval around the power value for the maximum efficiency. The power value for the maximum efficiency hmax can be calculated as follows:

$$S(\eta_{max}) = k \cdot S_r$$

with

k load factor ($k = \sqrt{\frac{P_0}{P_k}}$)

S_r Rated apparent transformer power

Note: The curve shape of the utilization profile is important for graphical comparisons. The influence of the utilization profile at higher power outputs is to be given more consideration than in case of lower power outputs. At the same time, attention should be paid to the question as to whether the higher investment for larger transformers is worth the expense, as besides increased space requirements the choice of suitable switchgear and protection devices must also be factored in.

In the comparison of efficiency curves in Fig. 4/1, the mean load value of the load curve under consideration is within the respective apparent power range $S(\eta_{max})$ ± 20 % of the 1,000-kVA and the 1,200-kVA transformer. For a cost evaluation of transformer service life (according to IEC 60364-8-1, VDE 0100-801 a minimum of 25 years should be assumed), investment and operation need to be considered (see bibliographical reference [4.1]).

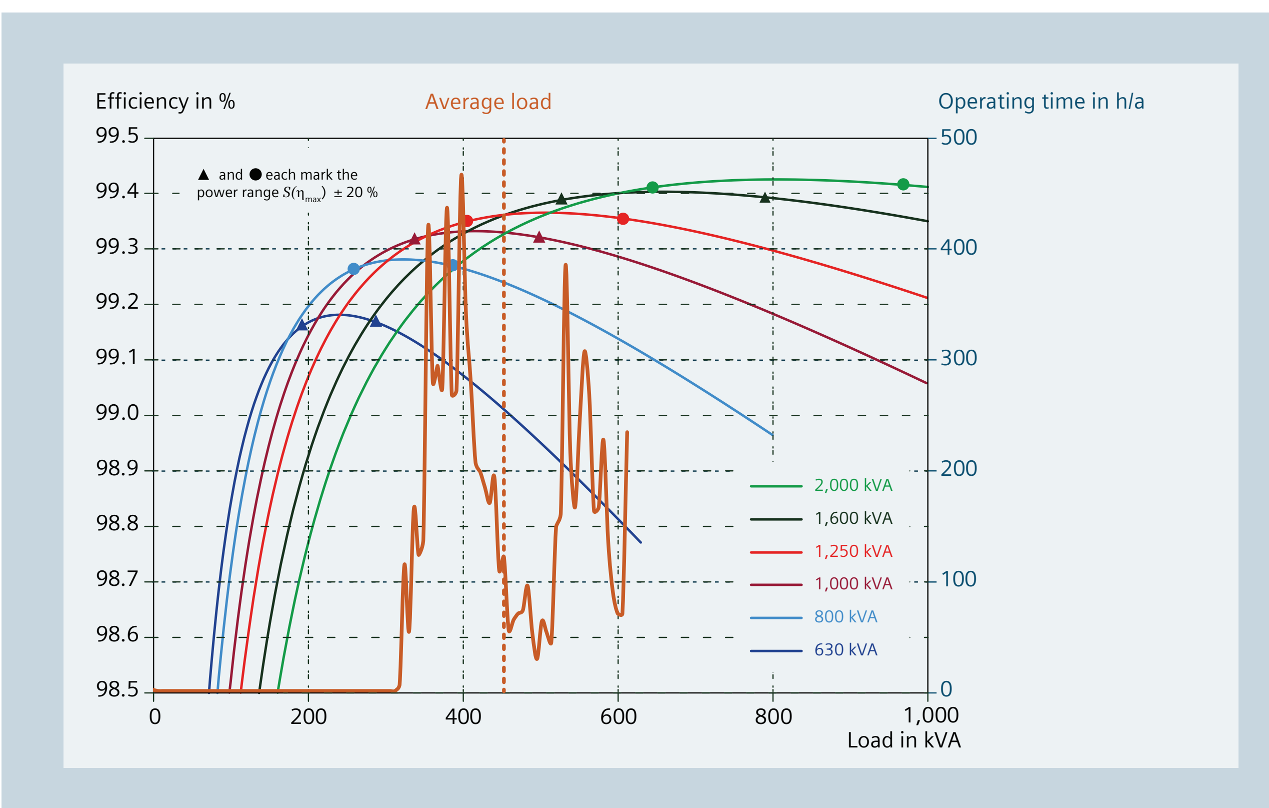


Fig. 4/1: **Comparison of efficiency curves for GEAFOL transformers and the utilization profile of a commercial plant with a maximum power demand of 610 kVA**

4.2 Operating performance of generators

Besides the output of active power, the generator's capacity to output reactive power plays an important part. In particular, capacitive loads may cause trouble as many generators reach their performance limits very quickly under capacitive load. Typically, the permissible generator power range is shown in the "P/Q diagram" (Fig. 4/2). There, the maximum permissible loading is plotted as a curve in the rectangular coordinate system with active power P as Y-axis and reactive power Q as X-axis. The active power factor cos φ identifies the angle to the respective operating points.

During plant operation it is expedient to measure the active power factor and compare it to the power rating of the generator deployed. Firstly, it is possible to integrate signalling of troublesome operating states in the load management, and secondly, a time-dependent recording of the active power factor (Fig. 4/3) can reveal whether reactive power compensation would be wise and which type it would be. In this context a distinction must be made as to whether the phase angle φ between voltage and current is greater (inductive load) or less (capacitive load) than zero.

Fig. 4/3 clearly reveals the problems with a representation of cos φ when electricity generated by a photovoltaic system is fed back into the grid. As long as there is no backfeed, cos φ is inductive. As soon as a just a little more PV power is available than needed for self-consumption and power is only fed back into the supply grid intermittently, the cos φ may oscillate between positive and negative values while the direction of current flow z continuously alters.

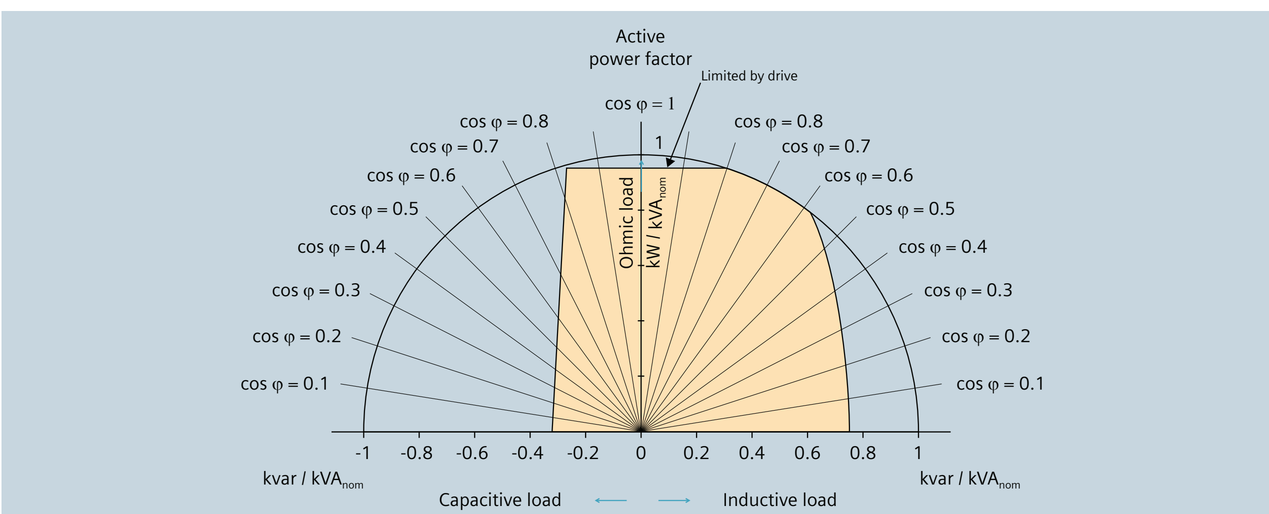


Fig. 4/2: **P/Q diagram for a generator**

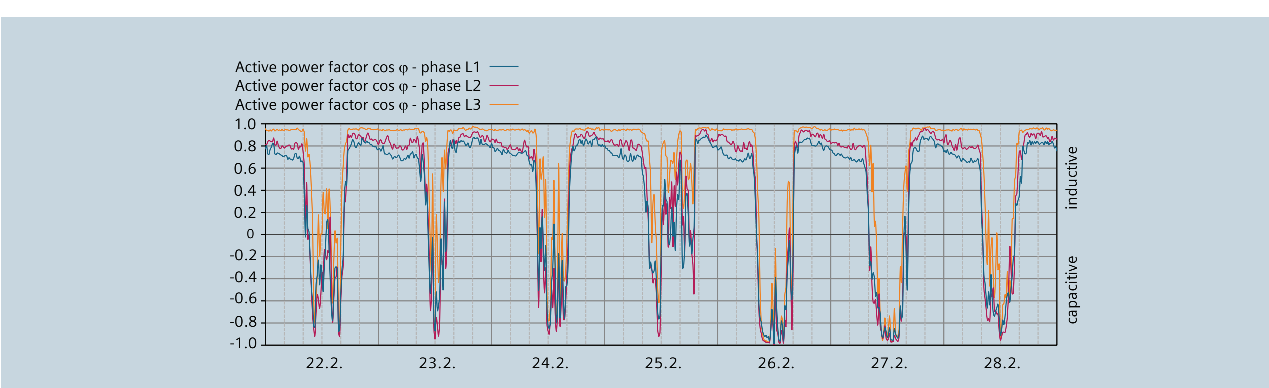


Fig. 4/3: **"Oscillations" of the active power factor when the direction of current flow alters due to backfeed**

4

4.3 Motor and assembly control and adjustment

Current and power measurements in the electric power distribution system are a cost-effective method of utilization control. To this end, the utilization profile must, however, be known for the operating motor or assembly. For this purpose, the current relating to specific operating points of the motor or the assembly can be measured and transferred to a utilization profile (Fig. 4/4).

Even when under no load, the motor or the assembly requires a certain amount of idling current. For electronic equipment, this is often called standby current. Eventually, loss, no-load currents, and standby currents yield the base load for electric power distribution.

If the utilization profile is linked to the load curve for current or power, a conclusion can be drawn about motor or assembly utilization (Fig. 4/5).

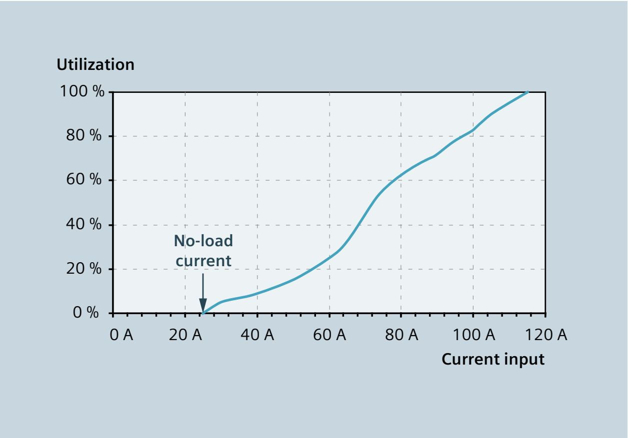


Fig. 4/4: **Example of a utilization profile**

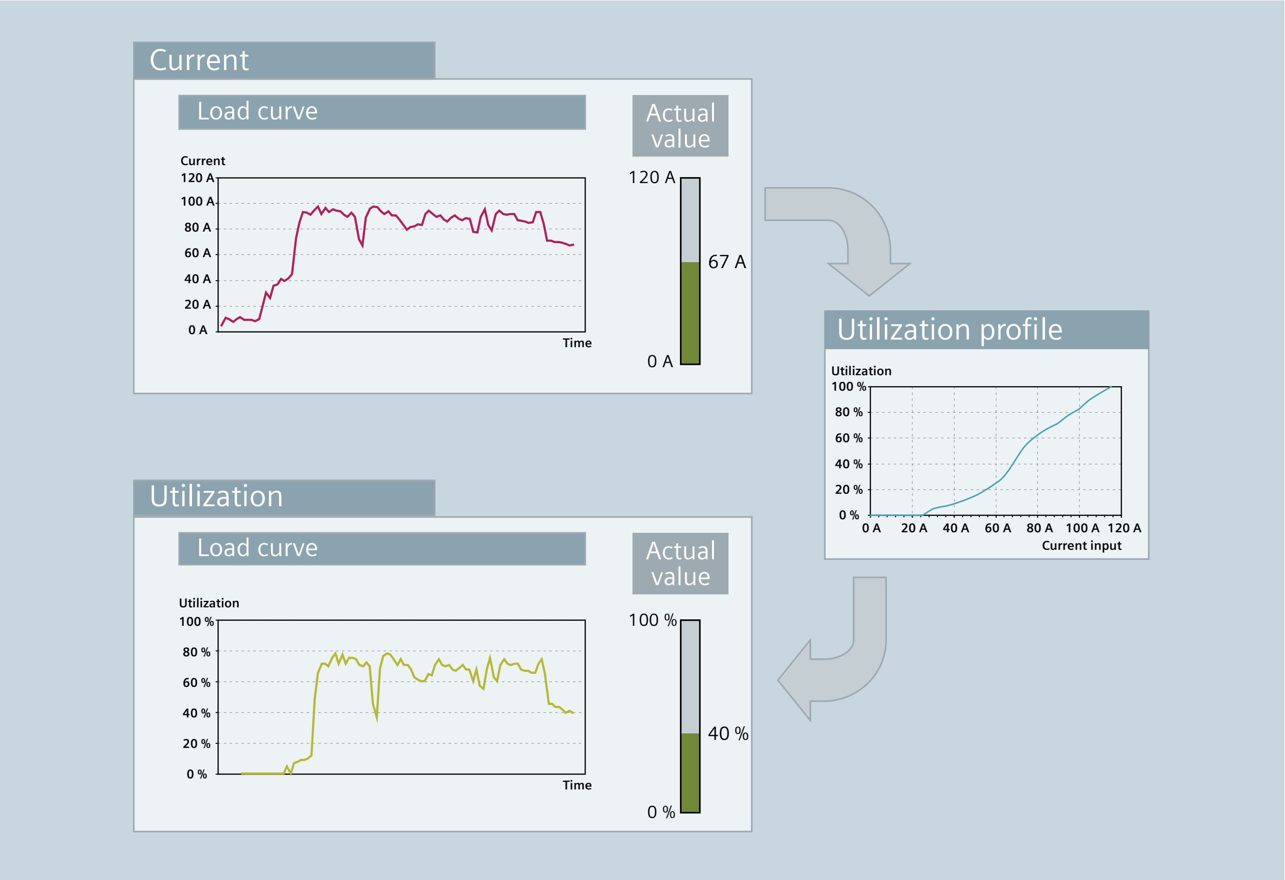


Fig. 4/5: **Translation of a current load curve into a utilization characteristic**

4

4.4 Distributed generation of electric energy

Operational management and availability of the power source play an important part in embedded (i.e. distributed) in-plant power generation. Combined heat and power stations are mostly heat-controlled and a virtually non-manipulable dependency on ambient conditions must be considered for renewable energy sources. The following description assumes in-plant use of the power generated only. Backfeed into the distribution grid of the distribution grid operator does not take place.

4.4.1 Renewable energy sources

Since there is to be no backfeed of electricity, the comparison between power generation and power consumption is important. There may be problems on weekends or bank holidays when plant utilization is low. The user will be on the safe side if the maximum amount of power which can be supplied by renewable power sources can just about serve the base load (Fig. 4/6). For the purpose of the example illustrated in Fig. 4/6, the power demand – even during lunchtime at weekends – should not fall below 400 kW.

A higher maximum power output becomes of interest if loads can be connected into supply or stepped up by way of load management, given that short-time power peaks are to be fed into the user's own power system. This can be planned if local weather forecasts (wind speeds for wind turbines and sunshine intensity for photovoltaic systems) – which have become remarkably good in the meantime – can be integrated into load management.

4

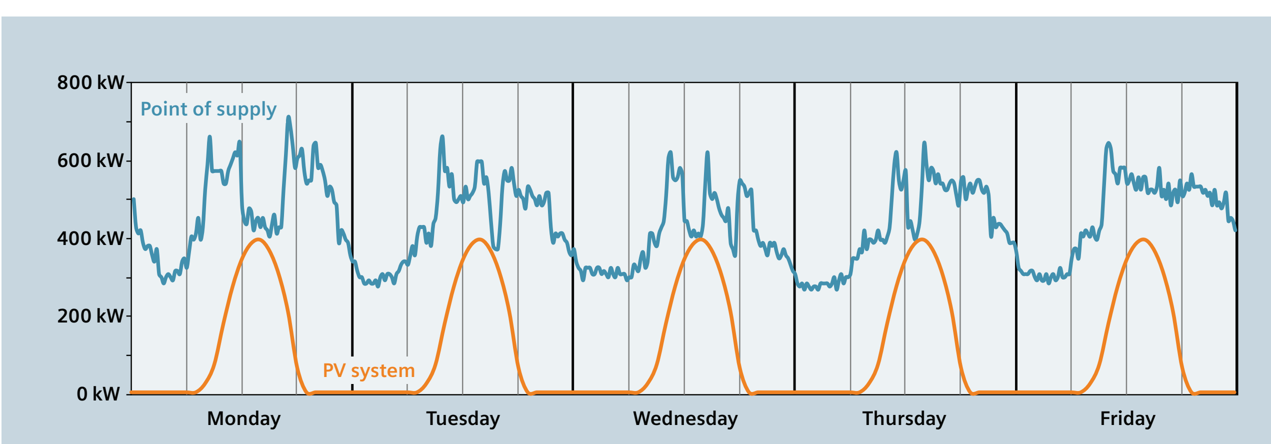


Fig. 4/6: **Comparison of a load profile with the theoretical capacity of a photovoltaic system (cell area size, cell performance, positioning, and site conditions playing a role here)**

4.4.2 Co-generation of heat and power

For dimensioning a combined heat and power plant (CHP plant), the load profile of heat demand must be evaluated, since CHP plants are normally heat-controlled. This means the plant only goes into operation if a there is a sufficiently high heat demand, for example, for heating or hot water generation. Then, electricity can be utilized, so to speak, as a waste product. Since a heat load profile of a building hardly allows predictions to be made about the relation between the size of the CHP plant and its profitability, the load profile is usually transformed into a frequency distribution for the heat demand (Fig. 4/7).

Dependent on the commercial conditions for a CHP plant, its operating time must be sufficiently long to be profitable, for instance 5,000 hours a year. The frequency distribution in Fig. 4/7 reveals a heat demand of 19 kW for an annual operating time of 5,000 hours. In the context of CHP plants, the ratio of heat to power is often assumed to be 60 : 40. This means that a CHP plant to supply 19 kW of heat is then capable of supplying about 12.7 kW of electric power. Considering a maximum heat demand of more than 200 kW, this may, in total, be regarded as a rather small contribution to heat generation as well as to power supply. During normal operation, the base load (electricity) is hardly reached and the CHP plant cannot be used for a peak load reduction either owing to the fact that it is heat-controlled.

Even if there was operating efficiency under a heat generating period of only 1,300 hours annually, the power output of the CHP plant would be a modest 27 kW thermally and hence 17 kW electrically. This would still be a very small plant. And an energy comparison for electric energy comes up with

12.7 kW · 5,000 h = 63,500 kWh

compared to

17 kW · 1,300 h = 22,100 kWh

which makes the operating efficiency of the CHP plant seem unrealistic for 1,300 operating hours from the perspective of electric power consumption.

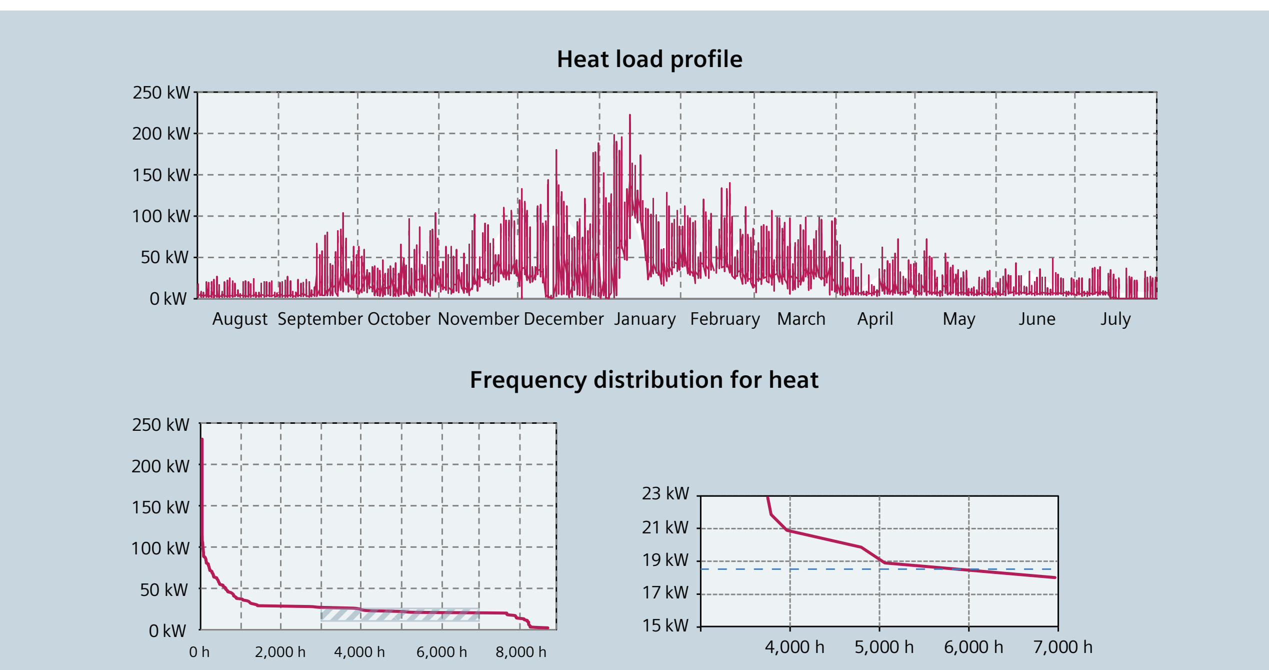
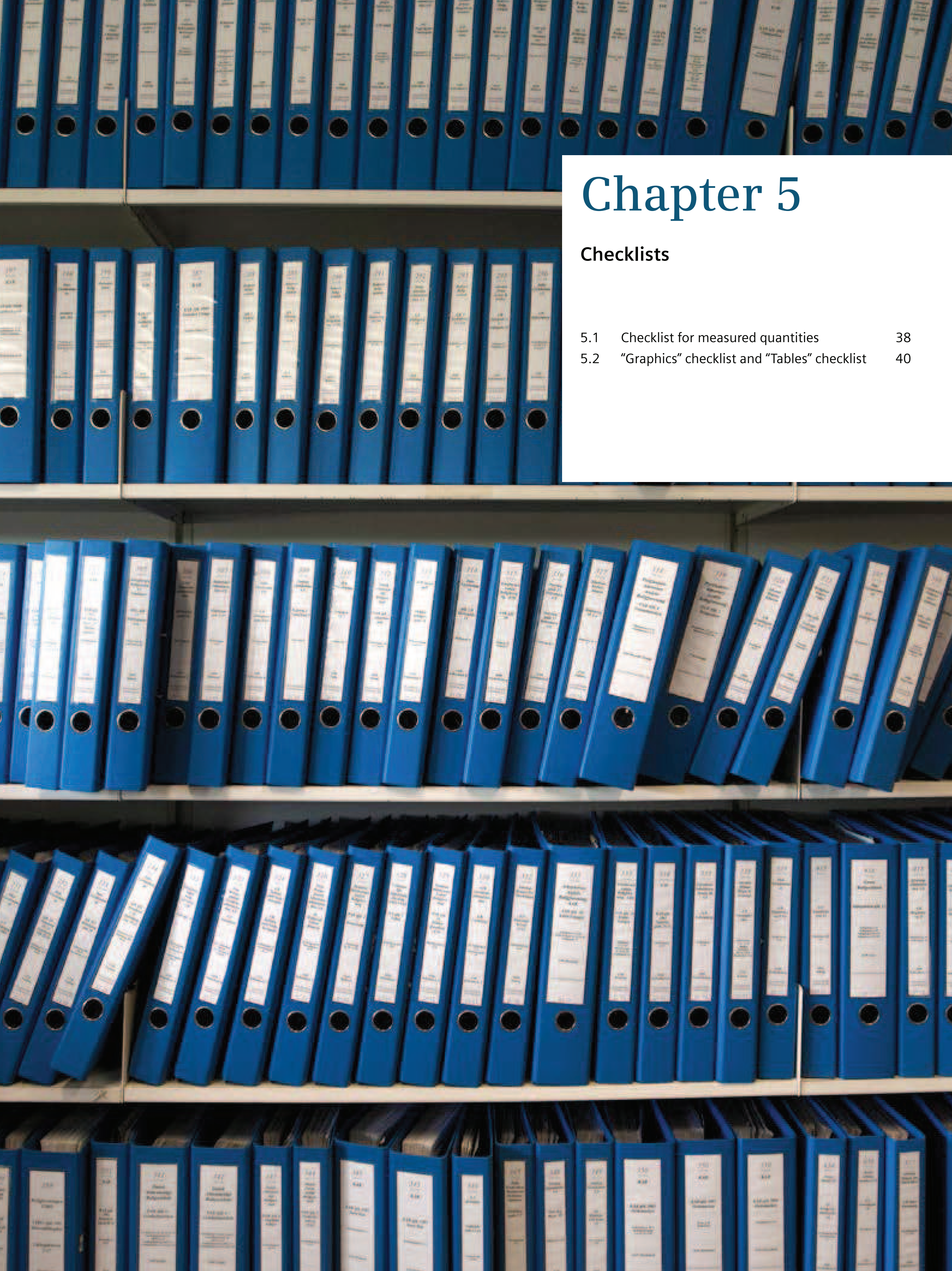


Fig. 4/7: **Load profile and frequency distribution for the heat demand; the cross-hatched area of the frequency distribution (bottom left) is shown enlarged at the bottom right**

4



Chapter 5

Checklists

5 Checklists

Checklists are suited for discussing project requirements and clarifying the scope of installations; in particular they are suitable for determining
- The type and number of measured quantities
- Display types for the desired graphics
- Characteristic value chart features

In these checklists, measured quantities, charts, and tables are split up according to the previously described levels of electric power distribution:
- Supply
- Transformer (check measurement)
- Generator, power generation plant
- Distribution level
- Load level
- Tenants (customer information)

For smaller customer-side power systems (up to about 300 kW), electricity supply is provided from the public low-voltage grid. Transformers are thus not necessary, but a check measurement may still make sense. Similarly, one's own generation of power using a generator is not always necessary.

5.1 Checklist for measured quantities

To characterize desired measured quantities, a simple checklist can be set up as early as in the planning stage. This checklist may, for example, be identified by the structural distribution level (supply, transformer, generator, main distribution system, ...) in the table header. Four columns of the checklist need to be filled in and optionally a comments column (examples are listed in Tab. 5/1).
- Number of measurements
- Description of the measured quantity (here including its physical symbol)
- Variant(s) of the measured quantity (for explanations see Tab. 5/2)
- Feature, for example to identify the direction of energy flow, and required certification

Tab. 5/2 acts as a fill-in assistant for the "Measured Quantities" checklist. The numbers for the variants and the small letters for the features help make the lists relatively transparent. This is due to the fact that data on a measured quantity usually fits into a line. The measured quantities are quarter-hourly mean values.
The energy values are given as multiplied by the factor of $4 \cdot h^{-1}$

Level (e.g. Supply, transformer, ...)				
Number of measurements	Measured quantity	Variant	Feature	Comment
1	W	①	a)	
...	...	...	...	...

Tab. 5/1: **Example for a "Measured Quantities" checklist**

5

Measured quantity/parameter		Variant		Feature [1)]	
U	Voltage in V	①	Single-phase measured quantity	a)	Purchase/import
I	Current in A	②	Measured quantities for each phase L1, L2, L3	b)	Backfeed/export
W	Active energy in kWh	③	Measured quantity as a summated value over all 3 phases	c)	MID-certified [2)]
W_Q	Reactive energy in kvarh	④	Measured quantities as values between phases L1-L2, L2-L3, L3-L1		
P	Active power in kW	⑤	Measured quantities as values between phase and neutral L1-N, L2-N, L3-N		
Q	Reactive power in kvar	⑥	Measured quantity for the neutral conductor N		
S	Apparent power in kVA				
cos φ	Active power factor				
λ	Power factor				
THD_U	Harmonic content in voltage in %				
THD_I	Harmonic content in current in %				

1) Only relevant for energy
2) Certified in compliance with the Measuring Instruments Directive 2004/22/EC

Tab. 5/2: **Fill-in assistant for the "Measured Quantities" checklist**

The sample table Tab. 5/3 looks into the supply point meter and measurements downstream of the transformer. Since there is no backfeed of electricity, only the purchase/import is recorded by the metering operator and transmitted to the customer. At the customer-side metering location downstream of the transformer, currents and apparent power values are acquired phase by phase as well as voltages between the phases. To assess the active power factor and the percentages of harmonic content in the voltage, the summated values over the individual phases are of interest.

5

Supply				
Number of measurements	Measured quantity	Variant	Feature [1)]	Comment
1	W	③	a), b)	Is provided by the metering operator, only data linking
Transformer				
Number of measurements	Measured quantity	Variant	Feature [1)]	Comment
1	U	⑤		
	I	②		
	S	②		
	cos φ	③		
	THD_U	③		

1) Only relevant for energy

Tab. 5/3: **Template for a "Measuring Instruments" checklist**

5.2 “Graphics” checklist and “Tables” checklist

To select graphics to be chosen for illustration, a simple matrix is sufficient (Tab. 5/4), where dots mark which graphic forms of representation are used for the different levels of electric power distribution. Tables and associated diagrammatic representations (bar charts, pie charts, or dots diagrams) can be used for tabular analysis (Tab. 5/5).

	Supply	Transformer	Generator	Distribution	Loads	Tenants
Load profile						
- Year						
- Month						
- Week						
- Day						
Frequency distribution						
- Year						
- Month						
Utilization profile						
- Year						
- Month						
Maxima evaluation						
- Year / Maxima sequence						
- Year / Day distribution						
- Month / Maxima sequence						
- Month / Day distribution						

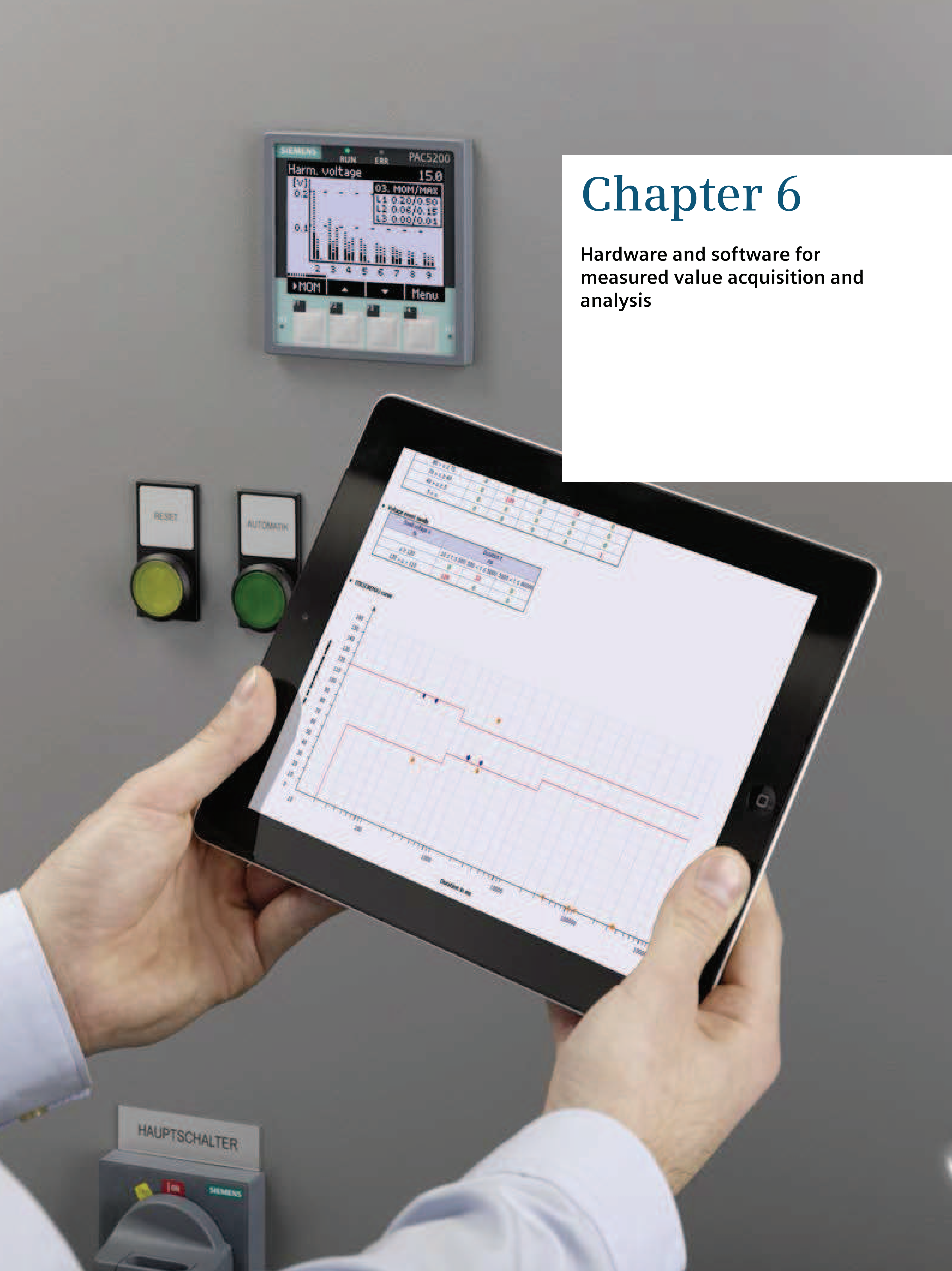
Tab. 5/4: **Checklist for graphic analyses on controlling**

		Supply	Transformer	Generator	Distribution	Loads	Tenants
Parameters, tabular							
Power	Maximum values						
	Minimum values (arithmetic)						
	Minimum values						
Energy	absolute						
	cumulated						
Peak load share							
Full load hours							
…							
Table values as graphics (bar charts, pie charts, …)							
Energy consumption and power peaks							
Power per month	Maximum values						
	Minimum values (arithmetic)						
	Minimum values						
Energy consumption	absolute						
	cumulated						
…							

Tab. 5/5: **Checklist for tabular analysis and the derived diagrams for controlling**

Chapter 6

Hardware and software for measured value acquisition and analysis



6 Hardware and software for measured value acquisition and analysis

Siemens provides a wide range of equipment and aids for acquiring and analysing measured values in an electric power distribution system. Using communication-capable switching devices, meters, multifunction instruments, and power system analysers it is possible to satisfy the most diverse user requirements as well as transmit information to data processing systems (Fig. 6/1).

Energy monitoring systems for the process and manufacturing industry can be set up using SIMATIC-based solutions (Fig. 6/2). Motor control units, frequency converters or variable speed drives, signal transmitters, and measuring instruments can be integrated as easily as communication-capable switching devices.

Tab. 6/1 on the next but one page provides a brief overview of the meters and measuring devices suitable for energy monitoring.

As apparent from Fig. 6/1 and Fig. 6/2, communication-capable switches and motor control units can be employed for data transmission as well as for making energy flows transparent. The electronic trip units of 3WL air circuit-breakers (ETU45B and ETU76B) and the 3VA2 moulded-case circuit-breaker can be linked to data transmission via Modbus, Ethernet, PROFINET or PROFIBUS - partly using optional interface modules. The measurement functionality of the 3VA2 with integrated Rogowski coils even equals those of a SENTRON 7KM PAC3200 when an ETU of series 8 is used, and additionally the 3VA2 measures active energy phase by phase (see Tab. 6/2 on page 44).

For industrial communication, the data is transmitted to a SIMATIC S7 controller. Tab. 6/2 provides an overview of the measured quantities and characteristic parameters which can be acquired by the different devices. In addition, those circuit-breakers and instruments for industrial use allow to acquire a great deal of status information and to control system operation.

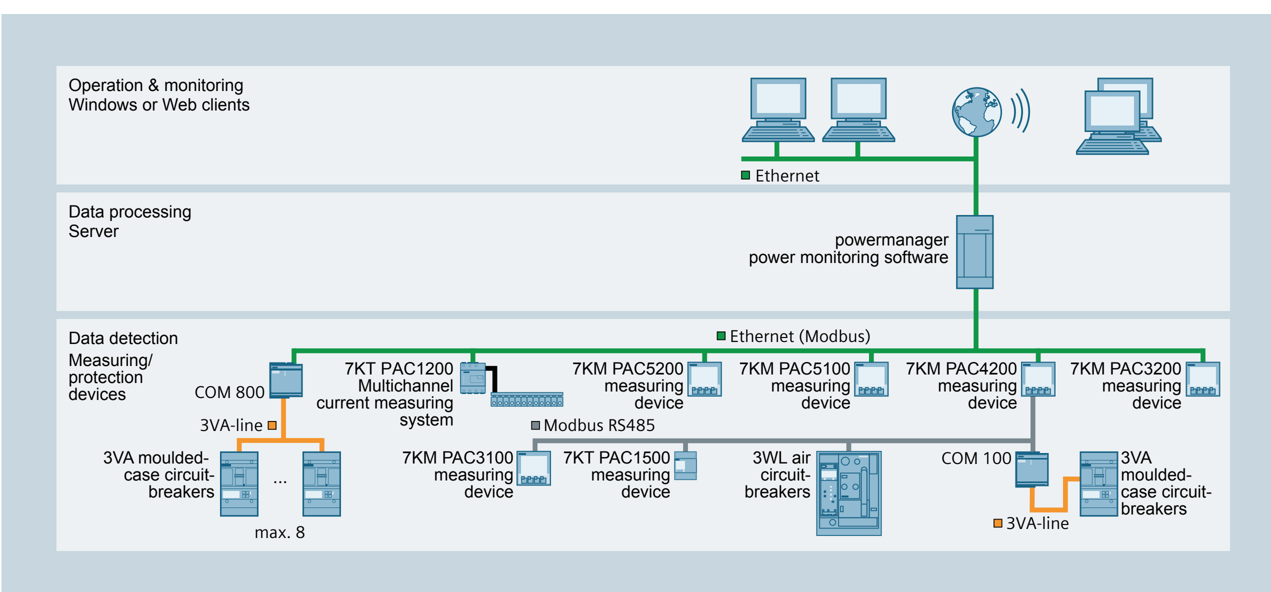


Fig. 6/1: **System design for energy monitoring in electric power distribution**

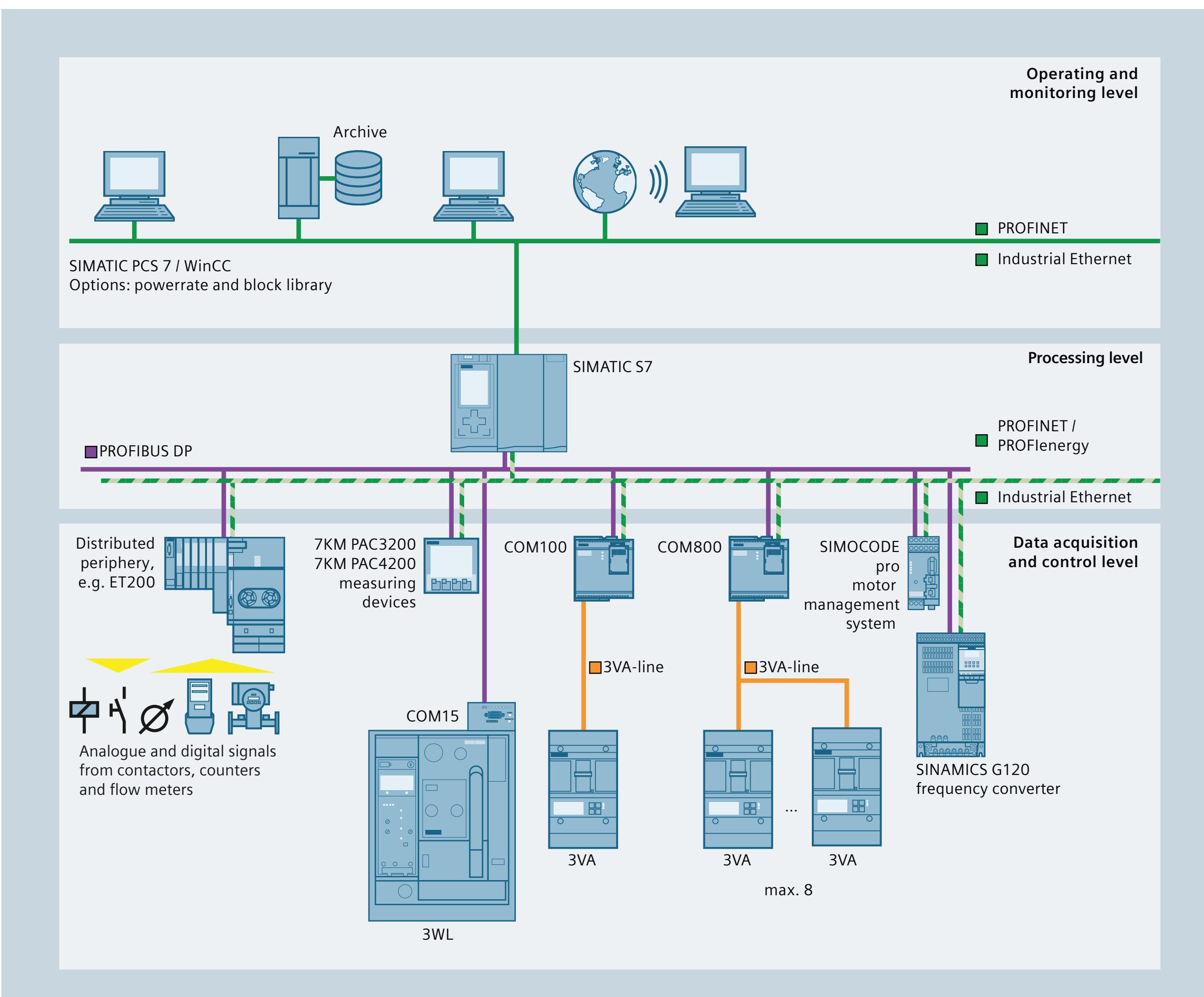
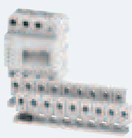
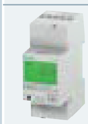
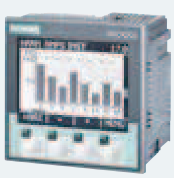
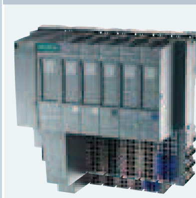


Fig. 6/2: **System design for energy monitoring in the process and manufacturing industry**

6

Equipment	Application	Standards	Use: Commercial	Use: Residential	Use: Industry
7KT PAC measuring devices					
 **7KT PAC1200 multi-channel current measuring system** • Modular device for measuring AC current • Data manger for DIN rail mounting • Sensors can be retrofit	Measurement of supplied and consumed power and energy, consumption values in ramified power systems of industrial plants, office buildings, infrastructure facilities, or holiday apartment complexes; local indication possible via web server and app. Modular design incl. sensor and data manager for displaying the energy consumption of up to 96 load feeders. The internal 1-GB-memory enables long-term data recording of up to one year.	EN 50470-1, EN 50470-3 IEC 62052-23, IEC 62053-31	✓	✓	✓
 **7KT PAC1500 measuring device** 1-/3-phase	For measuring consumption values in 1-phase or 3-phase power systems, e.g. in industrial plants, office buildings, or flats in multiple-family homes; also in compliance with the Measuring Instruments Directive 2004/22/EC (MID-certified) available.	EN 50740-1, EN 50470-3, IEC 62053-31 (IEC 62052-23 für 3-phasig)	✓	✓	✓
7KM PAC measuring devices					
 **7KM PAC3100 measuring device** AC/DC wide-range power supply unit, screw connection	Panel-mounted instrument with graphic display, integrated digital inputs/outputs and an RS485 interface for transmitting measured values or for configuring. Display of more than 30 electric parameters and consumption counts in switchgear substations, points of supply, or load feeders. International standards and multi-lingual display for worldwide use.	Energy measuring accuracy in compliance with IEC 61557-12	✓	--	✓
 **7KM PAC3200 / PAC4200 measuring device** 3 variants each: • AC/DC wide-range power supply unit, screw connection • DC extra-low voltage power supply unit, screw connection • AC/DC wide-range power supply unit with ring cable lug connection	Panel-mounted instruments with graphic display, user-configurable views, memory, clock and calendar function, digital inputs/outputs (PAC3200: 1DI/1DO); (PAC4200: 2DI2DO) and integrated Ethernet interface (PAC4200: with gateway function for measured-value transmission and configuration). Captures more than 50 (PAC3200) electric parameters in switchgear substations, points of supply, or load feeders. Plenty of functions for the precise energy parameter recording of electricity import and backfeed, PAC4200 additionally enables power quality assessment. The following expansion modules are available: • 7KM PAC Switched Ethernet PROFINET • 7KM PAC RS485 • 7KM PAC PROFIBUS DP • 7KM PAC 4DI/2DO (only PAC4200).	Energy measuring accuracy in compliance with IEC 62053-22/23 and IEC 61557-12	✓	--	✓
 **7KM PAC5100 / PAC5200 measuring device** 2 variants each: • Panel-mounted instrument with graphic display • Standard rail instrument without display	Panel-mounted instrument with graphic display and user-configurable views, or device for standard rail mounting in accordance with IEC 60715. Web server for parameterization, visualization, and data management. 2 binary outputs, electrically isolated voltage inputs, synchronization via internal RTC clock or externally via NTP, 4 user-parameterizable LEDs for signalling device status or limit-value violations, integrated RJ45 Ethernet interface. Captures more than 250 electric parameters in switchgear substations, points of supply, or load feeders. Plenty of functions for the precise energy parameter recording of electricity import and backfeed as well as power quality assessment. Only PAC5200: Flicker in compliance with IEC 61000-4-15, 2 GB memory, integrated fault recorder, reports based on EN 50160, r.m.s. value recorder.	Energy measuring accuracy in compliance with IEC 62053-22/23 and IEC 61557-12	✓	--	✓
SIMATIC ET 200SP AI Energy Meter					
 **AI Energy Meter ST module** Pluggable module for the SIMATIC ET 200SP peripheral system • For 1-phase and 3-phase power systems up to 400 V AC • Accuracy of ± 0.5 %	The SIMATIC automation system is widely used in industrial applications. These energy metering modules were developed to suit the scalable SIMATIC ET 200SP peripheral system for interfacing process signals to a central control unit. They boast of the full functional scope of a multi-function measuring instrument. Up to 42 AI Energy Meter modules can be plugged into a ET 200SP station. A module captures and calculates more than 200 values such as voltages, currents, phase angles, power, energy, and frequency. Typically, values are refreshed every 50 ms and cyclically or non-cyclically forwarded to the higher-level control unit. They can also be monitored from a web server and even exported as a .csv file for use in a PC-based spreadsheet program. More energy values from measuring instruments with pulse transmitters or with analogue interfaces can be forwarded to the modular SIMATIC ET 200SP system which can be equipped with up to 64 modules.	Measurement category CAT II, CAT III with guaranteed protection level of 1.5 kV for voltages in compliance with IEC 61010-2-030 Energy measuring accuracy in compliance with IEC 62053-22/23	✓	--	✓

Tab. 6/1: **Hardware for energy monitoring**

6

Measuring / switching device, meter module	SENTRON 7KT PAC1200	SENTRON 7KT PAC1500 [1)]	SENTRON 7KM PAC3100	SENTRON 7KM PAC3200	SENTRON 7KM PAC4200	SENTRON 7KM PAC5100	SENTRON 7KM PAC5200	SENTRON 3VA	SENTRON 3WL	SIMATIC ET 200SP AI Energy Meter ST
Energy										
Active energy - import summated $W_{\Sigma\text{-import}}$	●	●	●	●	●	●	●	●		●
Active energy - backfeed summated $W_{\Sigma\text{-back}}$	●	●	●	●	●	●	●	●		●
Reactive energy - import summated $Q_{\Sigma\text{-import}}$	●	●	●	●	●	●	●	●		●
Reactive energy - backfeed summated $Q_{\Sigma\text{-back}}$	●	●		●	●	●	●	●		●
Active energy phase W_{L1}, W_{L2}, W_{L3}	●	●	●	●	●	●	●	●	●	●
Power										
Active power phase P_{L1}, P_{L2}, P_{L3}	●	●	●	●	●	●	●	●	●	●
Active power summated P_{Σ}	●	●	●	●	●	●	●	●	●	●
Apparent power phase S_{L1}, S_{L2}, S_{L3}	●	●	●	●	●	●	●	●	●	●
Current										
Phase current I_{L1}, I_{L2}, I_{L3}	●	●	●	●	●	●	●	●	●	●
Neutral current I_N				●	●	●	●	●	●	●
Voltage										
Phase-to-phase voltage $U_{L1\text{-}L2}$, $U_{L2\text{-}L3}$, $U_{L3\text{-}L1}$		●	●	●	●	●	●	●	●	●
Phase-to-neutral voltage $U_{L1\text{-}N}$, $U_{L2\text{-}N}$, $U_{L3\text{-}N}$	●	●	●	●	●	●	●	●	●	●
Active power factor, power factor, harmonics										
Active power factor for phase cos φ_{L1}, φ_{L2}, φ_{L3}					●	●	●			
Active power factor summated cos φ_{Σ}						●	●			
Power factor for phase λ_{L1}, λ_{L2}, λ_{L3}	●	●		●	●	●	●	●	●	●
Power factor summated λ_{Σ}	●	●	●	●	●	●	●	●		●
Total harmonic distortion of voltage/current THD_U/THD_I				● [2)]	●	●	●		● [3)]	
Flicker according to IEC 61000-4-15							●			

[1)] Display only shows energy and power values. Further measured quantities are transmitted through optionally available expansion modules such as 7KT Modbus / 7KT M-Bus
[2)] THD-indication
[3)] Possible with measuring function „Plus“ and breaker status sensor

Tab. 6/2: **Overview of the measured quantities and characteristic parameters of measuring and switching devices**

6

To prepare the measurement data for use-specific processes, various application and task-specific tools are offered. The task matrix in Fig. 6/3 shall enable an initial assessment without going into details (see chap. 3). The level structure of the automation pyramid also defines the grid according to which the suitability of the software tools for the different automation levels is depicted. In addition, the tools are divided according to their areas of application. Tool classification may be regarded as a schematic guidance. Of course, a building management system will rarely be considered in the context of manufacturing processes.

With "Energy Analytics", Siemens furthermore provides a service programme which allows to choose services around energy management according customer demands. This programme combines energy transparency with the worldwide expertise acquired from various industrial sectors. Thanks to ongoing adaptation to dynamically changing conditions, continuous improvements can be achieved and verified for an energy management in compliance with ISO 50001.

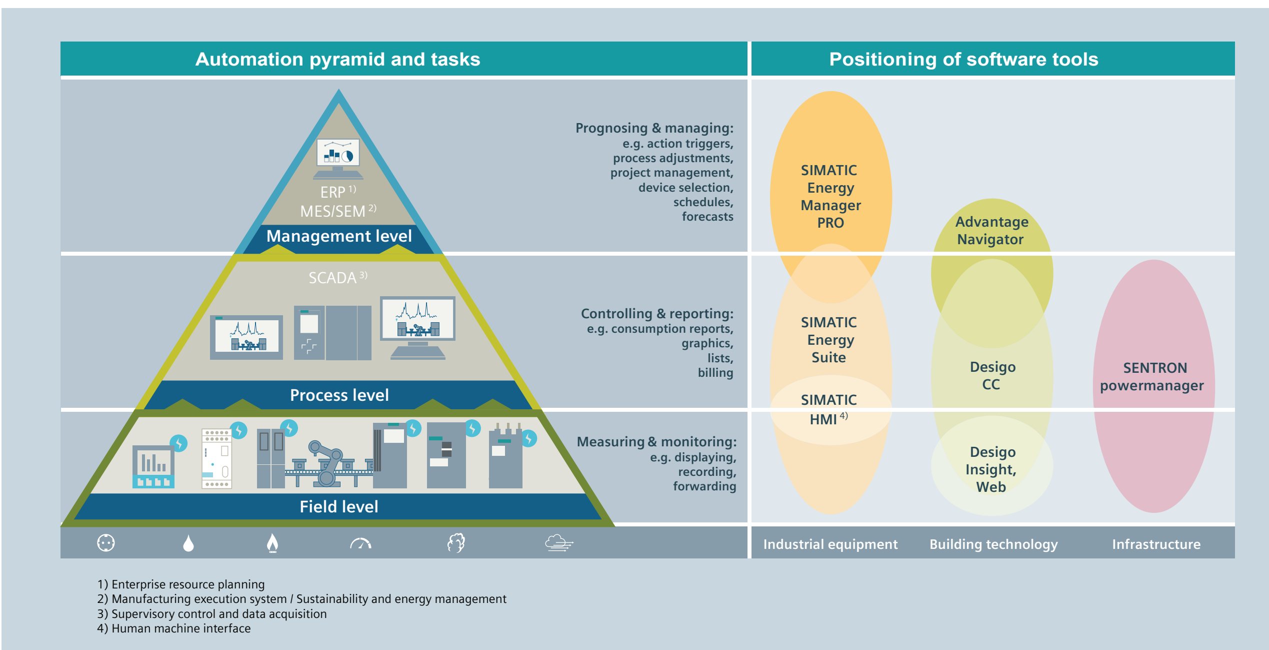
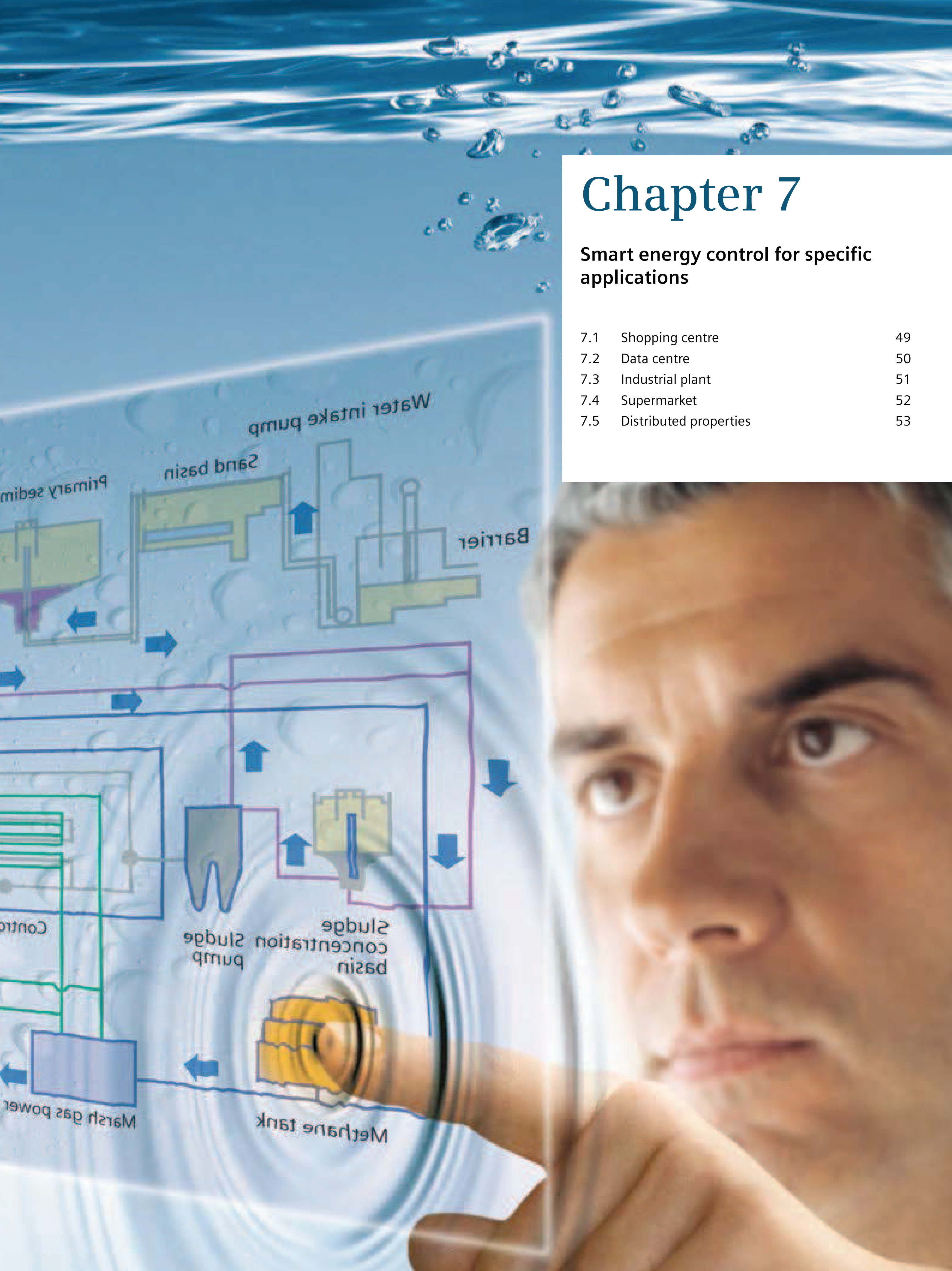


Fig. 6/3: **Positioning of the software tools provided by Siemens**

6



Chapter 7

Smart energy control for specific applications

7 Smart energy control for specific applications

Energy monitoring by way of measuring instruments which enables energy flows to be controlled and adjusted using appropriate analysis of the measurement data results in energy efficiency improvements (see Tab. 7/1) entailing

- Operating cost reductions
- Increase of plant availability
- Efficiency improvements in engineering

The examples of Fig. 7/1 to Fig. 7/5 on the following pages demonstrate methods of controlling through the creation of energy transparency (see the draft of the German VDI guideline VDI 2166 Sheet 1) as detailed below:

- Shopping centre
- Data centre
- Industrial plant
- Supermarket
- Distributed properties

Energy transparency leads to:		
Operating cost reductions by	**Increased plant availability by**	**Efficient engineering by**
Supporting the energy purchaser	Maximizing operating times	Parameterization instead of software programming
Profiting from lower demand charges	Avoiding overload situations	Time and cost savings by using software options
Improving energy cost awareness	Optimizing maintenance expenses	Integration into TIA and TIP
Optimizing capital investment	Assured power quality by continuous monitoring and analysis	No redundant data storage
Identifying energy-intensive equipment		Avoiding isolated information isles
		Design based on standard system interfaces

Tab. 7/1: **Customer benefits achieved by energy transparency**

7

7.1 Shopping centre

Billing individual store contractors in a shopping centre separately requires MID-capable measuring instruments within the European Union as of 19th April 2016 which comply with Directive 2004/22/EC and Directive 2014/32/EU for the certification of measuring instruments (EU Conformity Declaration). There is no need to rewrite certificates or approval documents. The EN 50470 standard series compiles the requirements placed on measuring instruments and their testing.

Measurement data for the individual stores depicted in Fig. 7/1 is acquired by 7KM PAC1500 devices and forwarded to the 7KM PAC4200 gateway via Modbus RTU. Data recording for commonly used equipment and loads such as escalators can be performed directly by communication-capable switchgear such as the 3VA2 circuit-breaker. For further processing with the powermanager analysis software, the data is transmitted to a Windows PC via Modbus TCP.

A power demand of approx. 14 kW in total is assumed for the four escalators depicted, so that an average operating time of 10 hours a day results in an energy demand of approximately 140 kWh. In Fig. 7/1 only a few stores are highlighted as examples and measurements of power supply to the specified items of equipment are summed up. The energy consumption total takes account of the other shops and stores as well as corridor lighting.

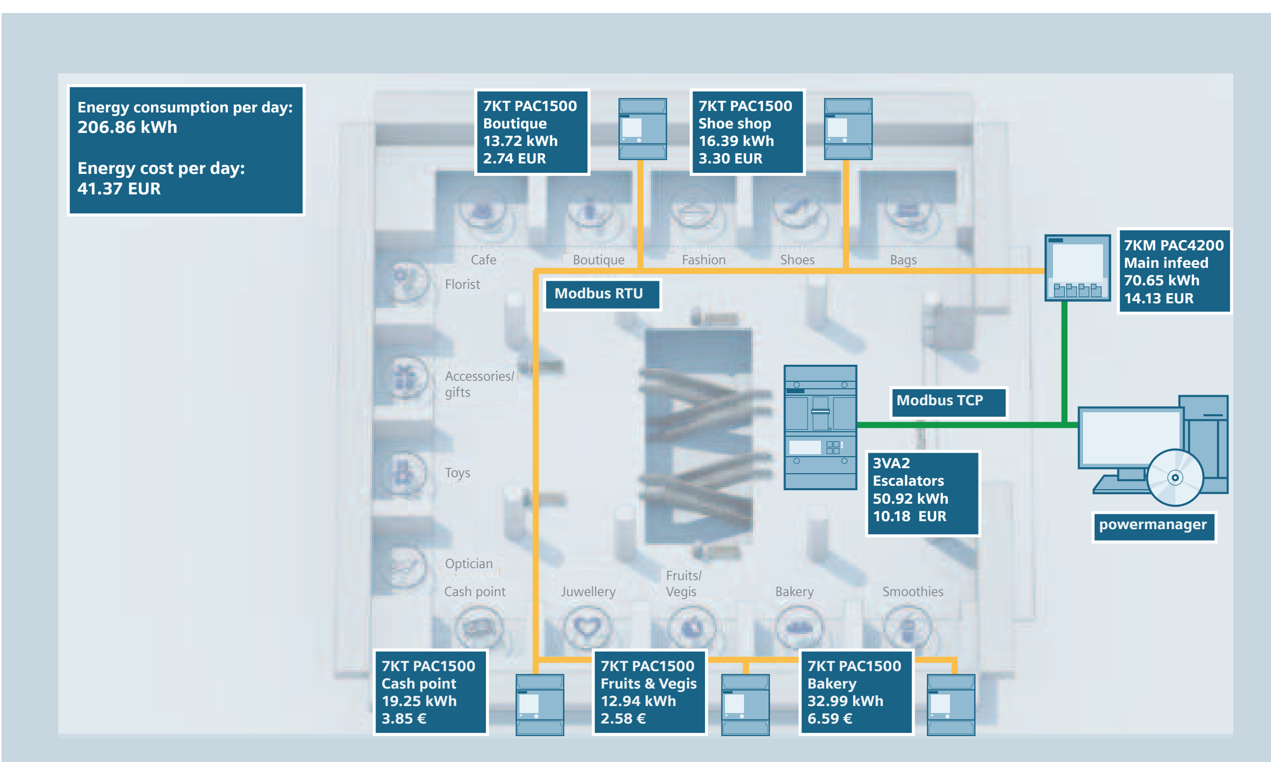


Fig. 7/1: **Energy monitoring of a shopping centre**

7

7.2 Data centre

For the data centre in Fig. 7/2, a redundancy concept with two separate rooms being supplied is considered where the server racks are supplied from two separate busbar trunking systems. Bibliographic reference [7.1] provides a comprehensive description of power supply for data centres.

Racks can be power-supplied from standard-type trunking units for the BD2 distribution busbar system. Orders may include suitable measuring instruments as well. The individual 7KM PAC3100 measuring devices in the load feeders to the racks are interfaced through the 7KM PAC4200 gateway instruments located in the busbar trunking units of the SIVACON 8PS busbar trunking systems type LI.

Fig. 7/2 only shows the analogue distribution busbar in the two redundant rooms as an example. The data demonstrates a good energy efficiency since the PUE value (i.e. the power usage efficiency, meaning the ratio of total energy consumption in relation to the energy consumption of the ITC equipment; ITC: information and communication technology) is only 1.5 in the server rooms.

Energy measurements of data centre air conditioning can be undertaken by the 3VA2 moulded-case circuit-breaker. For the UPS installations (UPS: uninterruptible power supply) it makes sense to use 7KM PAC5200 measuring devices for determining power quality characteristics.

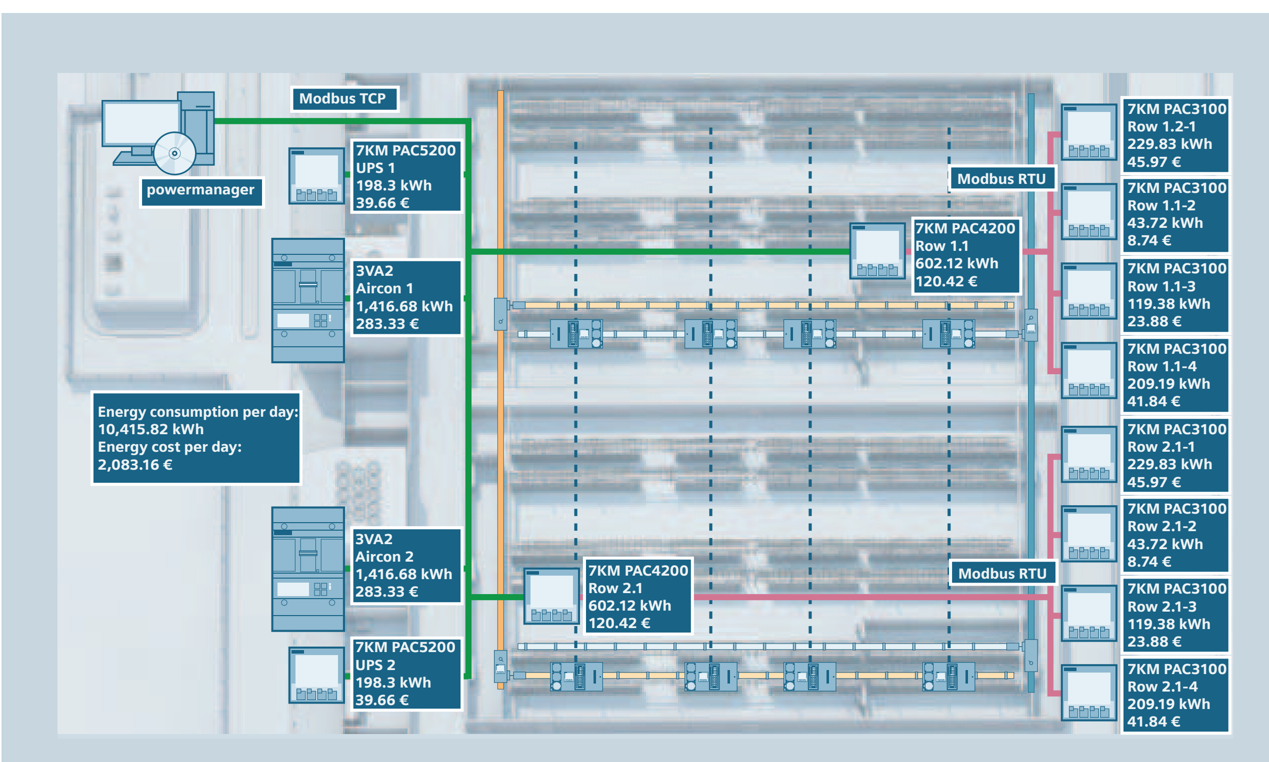


Fig. 7/2: **Example of energy monitoring in a data centre**

7.3 Industrial plant

In order to keep expenses low in a harsh industrial environment, a concept for central energy monitoring is drafted in the Fig. 7/3 example. The measured values for the supply and the load feeders are processed in the SIVACON S8 motor control center. The 3WL air circuit-breaker in the supply circuit communicates with the distributed SIMATIC ET 200SP peripheral device via PROFIBUS.
Connection to the central SIMATIC S7 automation controller is per Profinet. Thanks to a Profinet communication module, the SIMATIC ET200SP station can also communicate with the 3VA2 moulded-case circuit-breaker for the supply feeder of the pumps. The plug-in AI Energy Meter modules for the SIMATIC ET 200SP acquire the instrument transformer data from the other load feeders of the SIVACON S8. For the purpose of comprehensive energy monitoring further modules with digital inputs and outputs can be used.

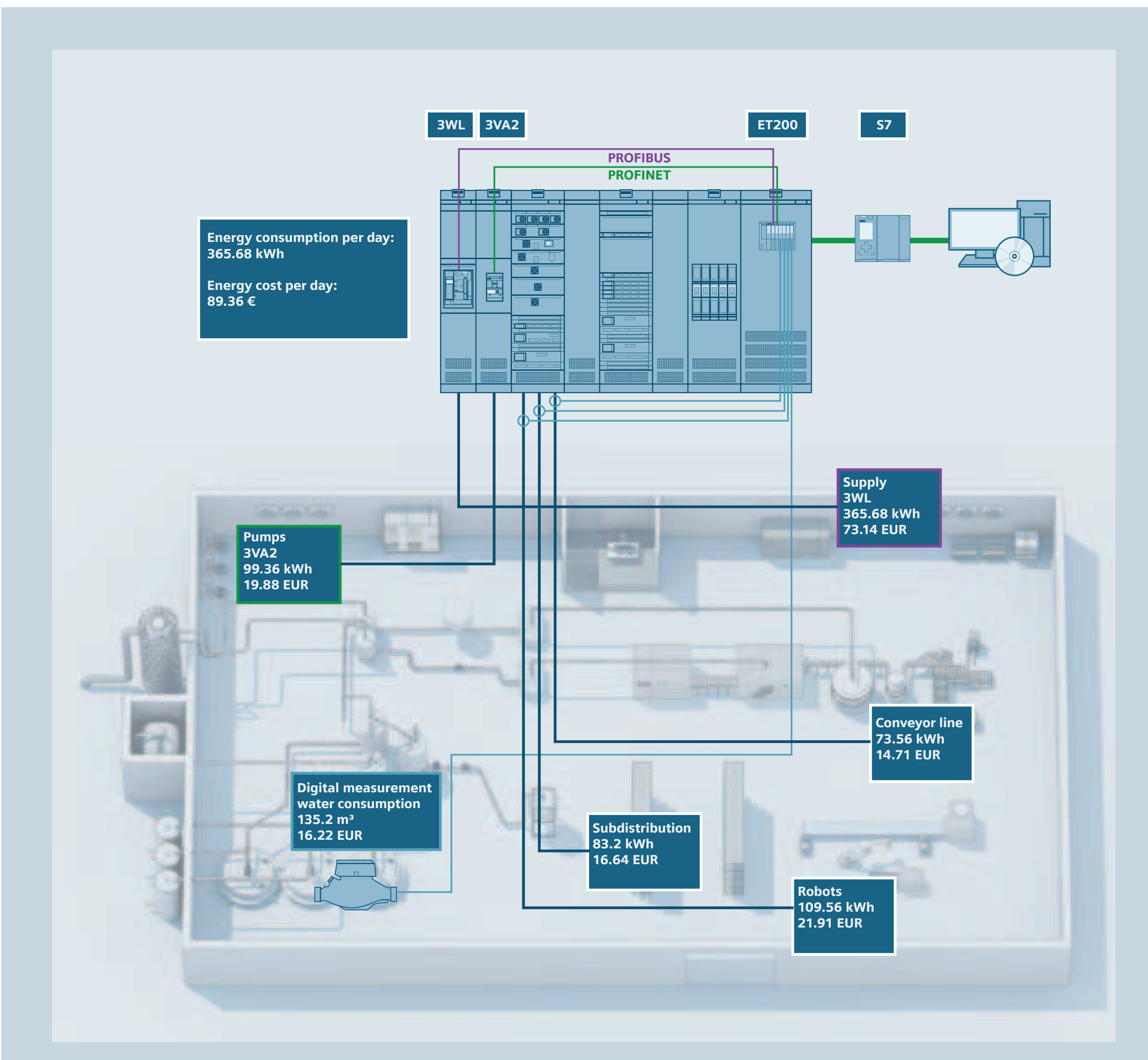


Fig. 7/3: **Components for energy monitoring in an industrial environment**

7

7.4 Supermarket

Since only an overview of energy consumption of individual items of equipment is required in a supermarket, and as this data is not required for billing purposes, it is not necessary to use MID-capable measuring instruments. The 7KT PAC1200 multi-channel current measuring system, which can be rapidly and flexibly installed, enables data acquisition from load centres such as cooling equipment, baking ovens or checkout areas (Fig. 7/4) and evaluation from a PC using a web browser or a specific web server app (iOS and Android) for 7KT PAC1200, or using the SENTRON power manager. As central data acquisition in the switchgear substation is sufficient, the only requirement is communication interfacing of the data manager to a PC.

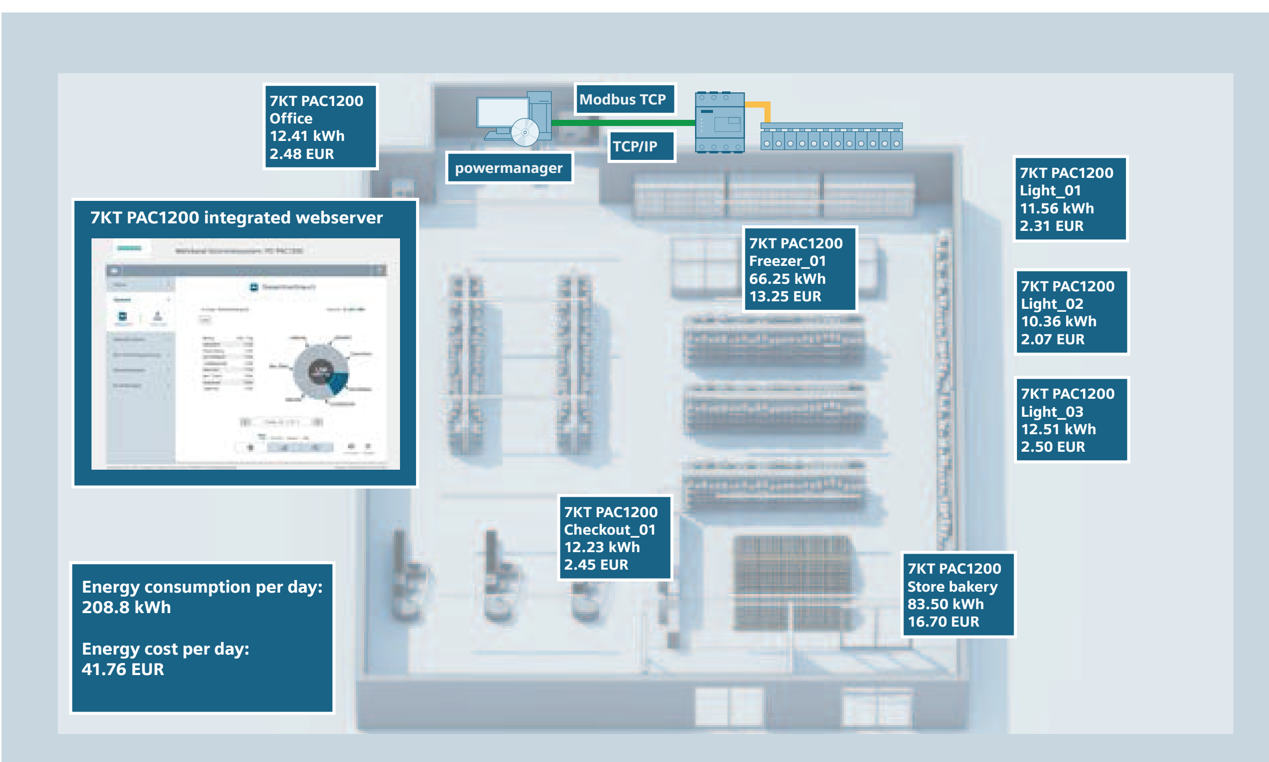


Fig. 7/4: **Components for energy monitoring in a supermarket**

7.5 Distributed properties

To obtain an overview of costs and electricity consumption of the infrastructure in rural or municipal communities, gateway-compatible multi-function meters are deployed at the individual locations. Data is transmitted via TCP/IP to a central institution and can be processed with the SENTRON powermanager PC tool (Fig. 7/5). The data can be an important aid in municipal and local district planning. Of course, the measurement data of SIMATIC automation systems – comparable to industrial solutions as typically used in the sewage treatment or the waste incineration plant – can also be transmitted.

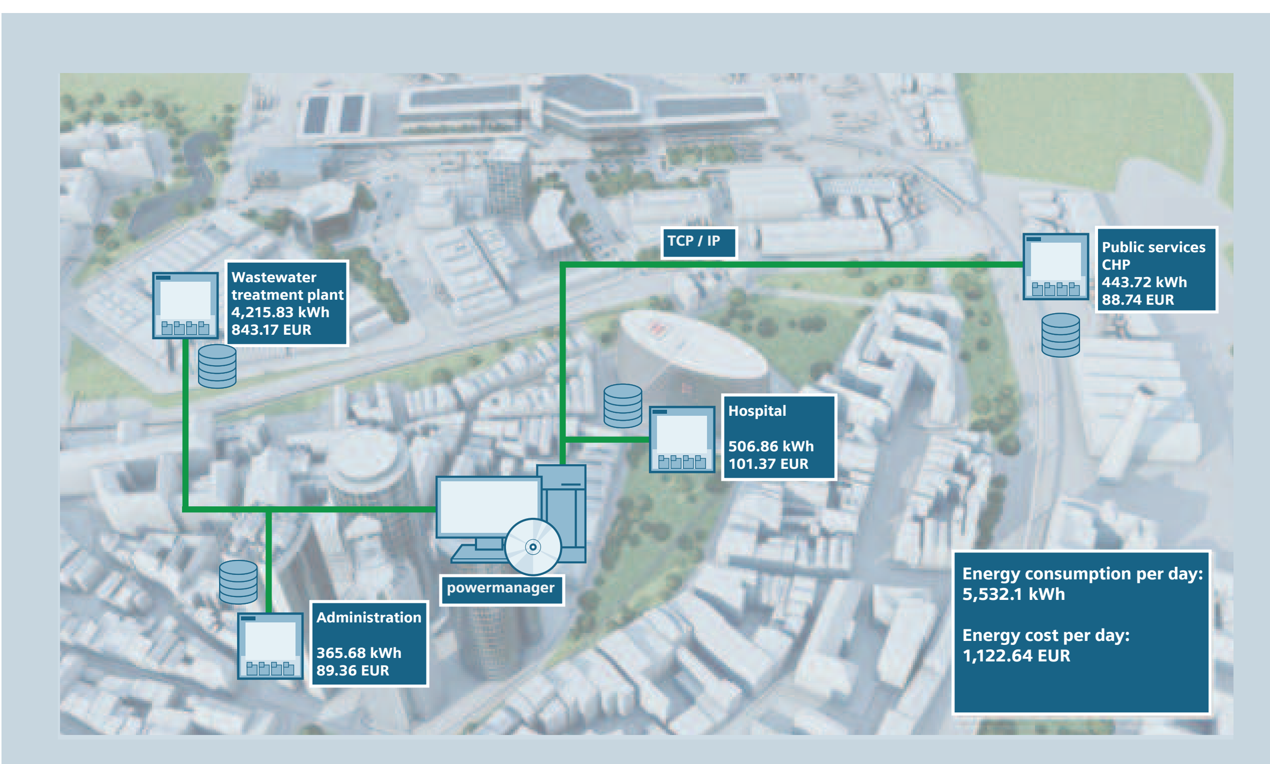


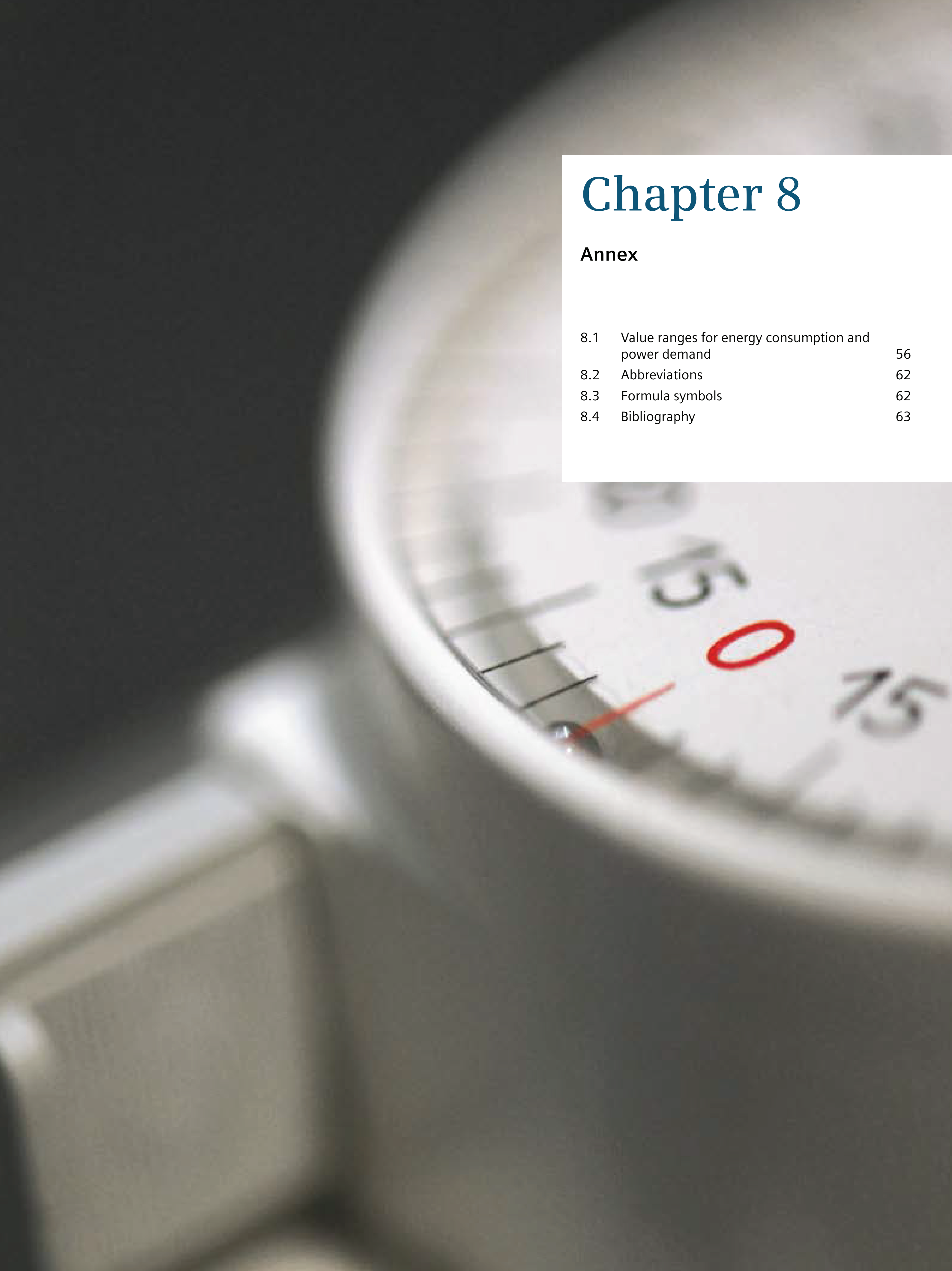
Fig. 7/5: **Components for energy monitoring in distributed properties**

7

7

Chapter 8

Annex



8 Annex

8.1 Value ranges for energy consumption and power demand

Experiences gained from the energy monitoring of a certain building type can also be an aid for the planner when he is working on new projects. It is important in this context to know the boundary conditions relating to such specifications, so that planner can classify and structure the own project specifications according to logical aspects. For this reason, the Annex exemplifies technical data of office buildings as found in the relevant literature.

As early as in the initial phases of planning (establishment of basic data, preliminary planning, concept planning, see [8.28]) energy saving and environmental compatibility play an important part; the IEC 60364-8-1 standard, for example, was published under the heading "Energy efficiency". Therefore it must be possible at times where the planner doesn't yet have detailed information about the distribution structure and consumption patterns to make a rough estimate of the energy and power demand for the electric power supply system which will eventually be the basis for initial dimensioning and cost estimates.

The accurate distinction between energy consumption and power demand must be given due consideration, since the energy cost (the product of energy consumption and kilowatt per hour rate) and the power cost (= power demand multiplied by the demand charge) may contribute to the total cost to a different extent. As described in chap. 2, the peak factor is an important value which is linked to the annual operating hours:

$$P_{peak} = k_{peak} \cdot W_{mean} / 8{,}760 \text{ h}$$

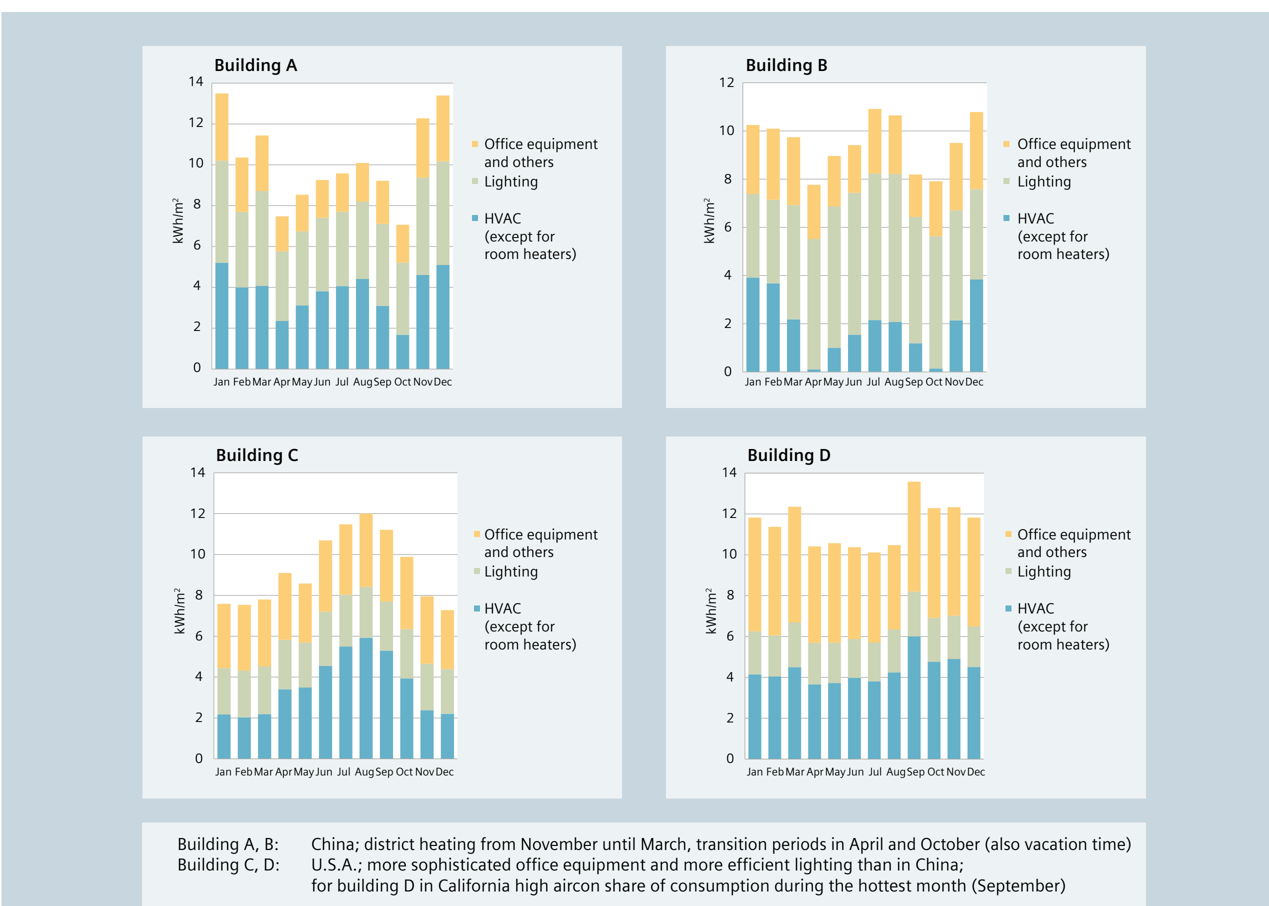


Fig. 8/1: **Monthly load values for four different buildings in China and the U.S.A. [8.7]**

$W_{mean} = P_{peak} \cdot t_{mean}$

where

P_{peak} Maximum power demand

k_{peak} Peak factor (= P_{peak} / P_{mean})

W_{mean} Annual energy consumption

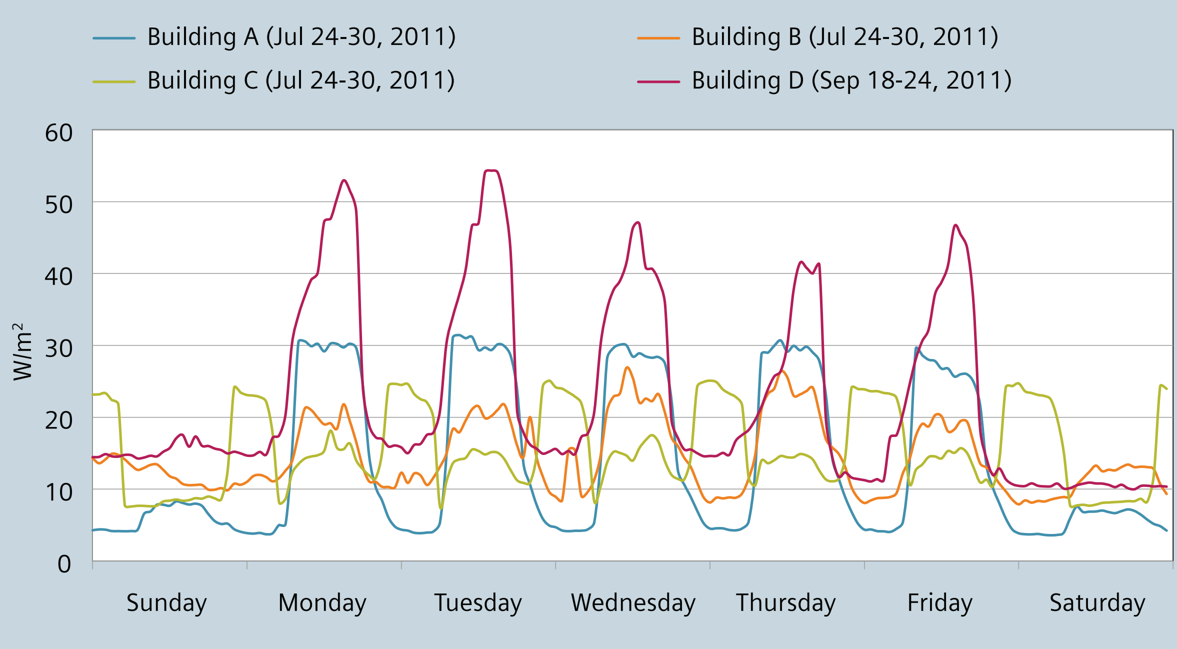
t_{mean} Annual operating hours (use period)

Resulting in:

k_{peak} = 8,760 h / t_{mean}

Note: This simple correlation between k_{peak} and t_{mean} only applies to approximately rectangular load curves. Averaging "obscures" peaks and time dependencies.

The measured values are quarter-hourly mean values, so that safety margins must absolutely be factored in. In addition, planning must consider seasonal dependencies as well as the fact that weather conditions and terms and conditions of use differ locally and may possibly change during the intended operating period. Fig. 8/1 shows the monthly electricity consumption for a year per square metre for four different buildings in China and the U.S.A., see [8.7]. An evaluation of the energy consumption of the four buildings during one week also illustrates differences due to usage and framework conditions (Fig. 8/2). It becomes clear that there will never be a simple model for estimating the power and energy demand of a building (here exemplified by office and administrative buildings).



Building A, B:	China; for A typical, slight decrease on Friday afternoons
Building C:	U.S.A.; consumption peaks at night due to electric water cooling for remote cold (used at daytime)
Building D:	U.S.A., California; aircon at hottest daytime in September, PV system use to reduce peak load would be conceivable

Fig. 8/2: **Typical weekly load curves for four different buildings in China and the U.S.A. [8.7]**

8

Some empirical and reference values obtained from the literature about the electricity consumption of office and administrative buildings have been compiled in Tab. 8/1. Fig. 8/3 shows the bandwidth of possible electricity consumption figures gained from the analysis of approx. 400 office buildings in one country [8.13]. Similarly, the different framework conditions and possibilities prevailing in different countries become apparent (Fig. 8/4). Furnishing and amenities, intended use and the different technical means play at least as much a part as the energy efficiency of individual components. The splitting of electricity consumption according to applications shown in Fig. 8/5 may only be regarded as an example.

Countries with a temperate climate have a significantly lower demand for heating, ventilation, and air conditioning than northern regions or countries with a more humid climate such as Singapore. In Norway, natural water power as native source of electricity is also used for heating, whereas Great Britain uses gas for this purpose, and in Germany a mix consisting largely of oil, gas, wood, and electricity is also used for heating. It is, however, conceivable that heating and hot-water preparation by means of electricity will experience a renaissance due to renewable electricity generation.

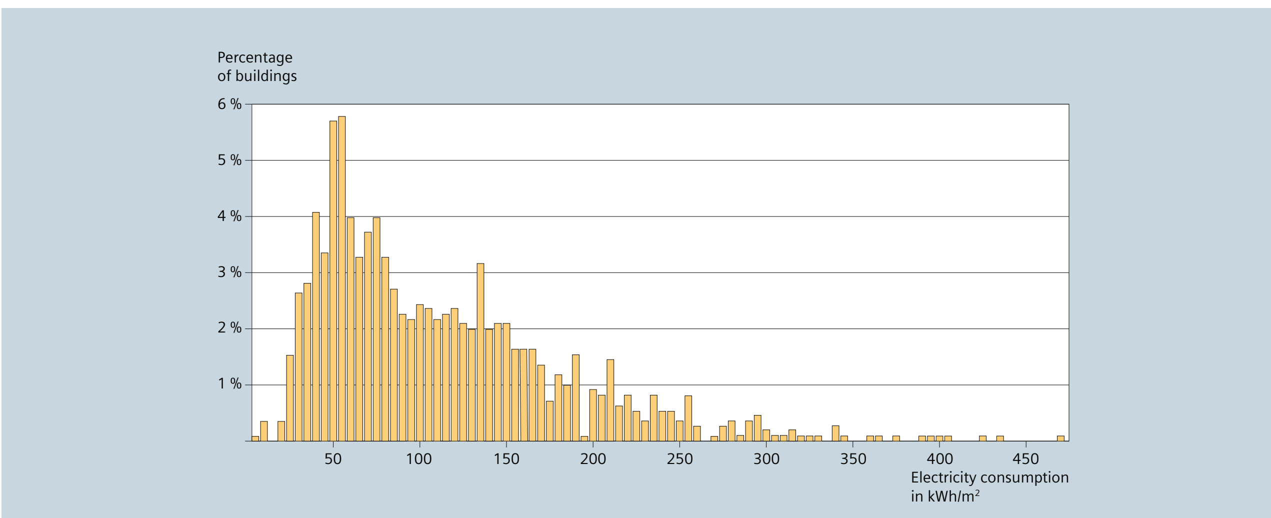


Fig. 8/3: **Statistical analysis of electricity consumption of office buildings in Czechia [8.9]**

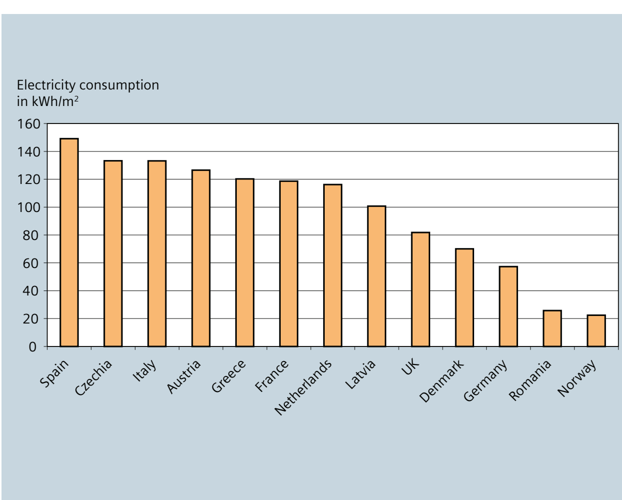


Fig. 8/4: **Annual electricity consumption of office buildings in different European countries [8.16]**

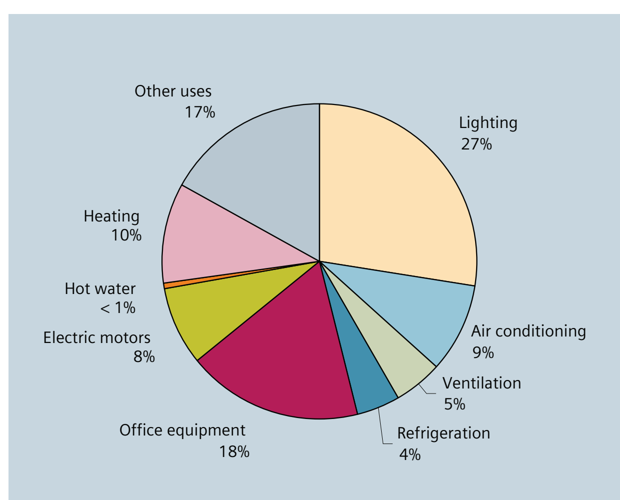


Fig. 8/5: **Example of electricity consumption in offices split according to application [8.16]**

Country	Source	Energy consumption in kWh per m^2 NFA and year	Features, type	Ref.
Germany	Federal Ministry for Economic Affairs and Energy	35	Office building, only heated	[8.1]
		85	Office building, tempered and ventilated	
		105	Office building with full air-conditioning system	
	VDI guideline 3807-2	22 (reference value 12)	Administrative building	[8.2]
	Stadt Heidelberg	Range 35 - 120	Office building, standard design	[8.3]
		Range 25 - 45	Office building, efficient design	
Switzerland	SFOE	106 (Range 46 - 133)	Office building	[8.4]
Austria	O.Ö. Energiesparverband Analysis of 1997	143 1) (Range 31 - 380 1))	7- 800 employees in the building; 380 - 28,400 m^2 GFA Furnishing differences as to ventilation and air conditioning as well as data centre, kitchen and canteen	[8.5]
	ÖGUT Stromsparen 2011 [Saving Electricity 2011]	Below 30 (low consumption)	Without ventilation and heating	[8.6]
		30 - 80 (medium consumption)		
		Above 80 (high consumption)		
U.S.A. / China	Tsinghua University (China), LBNL, ORNL (U.S.A.) (see Fig. 8/1 and Fig. 8/2)	122	Building A - China	[8.7]
		114	Building B - China	
		111	Building C - U.S.A.	
		137	Building D - U.S.A.	
		117	Mean value of 513 office buildings - China, Bejing	
		154	Mean value of 112 office buildings - U.S.A., California	
U.S.A.:	CBECS 2012 (US EIA)	139 1)	Office building with a GFA of 93 - 929 m^2	[8.8]
		173 1)	Office building with a GFA of 930 - 9,290 m^2	
		230 1)	Office building with a GFA of 9,300 m^2 and more	
Czechia	Enectiva - Blog	110 (Range 50.1 - 142.7)	Analysis of 400 administrative buildings (see Fig. 8/3)	[8.9]
UK	CIBSE Guide F	33 (GP 2)), 54 (typical)	Building "type 1": naturally ventilated, simple, often cellular offices; approx. 100 to 3,000 m^2 (treated floor area)	[8.10]
		54 (GP 2)), 85 (typical)	Building "type 2": naturally ventilated, open-plan offices with some office cellular offices and special rooms; more amenities than with "type 1"; approx. 500 to 4,000 m^2 (treated floor area)	
		128 (GP 2)), 226 (typical)	Building "type 3": air conditioning, standard design; approx. 2,000 to 8,000 m^2 (treated floor area)	
		234 (GP 2)), 358 (typical)	Building "type 4": air conditioning, premium design; often company headquarter; high-class standard of amenities; approx. 4,000 to 20,000 m^2 (treated floor area)	
Belgium	EURAC research iNSPiRe Project	100 -160	Ventilated; quite many rather old buildings (> 50 years)	[8.11]
		150 - 220	Air conditioned; quite many rather old buildings (> 50 years)	
Greece	EURAC research iNSPiRe Project	70 (Range 62 - 88)	Range marks dependency on climatic zones (from approx. 42 in 1980 grown to 70 in 2010)	[8.11]
Italy	EURAC research iNSPiRe Project	120		[8.11]
Finland	TU Delft	97		[8.12]
Netherlands	TU Delft	88		[8.12]
Norway	Statistics Norway	202 1)	Electricity from hydro-electric power stations frequently used for heating	[8.13]
Sweden	SINTEF Energy Research	108		[8.14]
Singapore	BCA	240 (Range 180 - 420)	Extreme values: minimum approx. 50 - maximum approx. 1,667 kWh per m^2 NFA and year	[8.15]
European Union	Intelligent Energy Europe	84 (Range 55 - 156)	Analysis of 53 office buildings in Europe (see Fig. 8/4); mean values for the individual applications (see Fig. 8/5)	[8.16]

1) data for gross floor area multiplied by factor 1.1 (GFA = 1.1 * NFA)
2) GP: good practice; characterizes the use of known and well-established, energy-efficient management and characteristics
typical: typical for existing stock of office buildings

Tab. 8/1: **Bibliographical reference for the energy consumption of office and administrative buildings**

The power demand for electric power distribution can be derived from the mean annual energy consumption values by approximation if the mean annual use period (i.e. operating time) is known. The annual use period is defined as the period within a year which would be sufficient to supply the whole annual energy demand if all loads would have to be continuously supplied in full, that is if the planned peak power output would be required throughout this period.

This can only be an approximation, since this model assumes a load curve shape which is nearly rectangular. This approximation can only provide a lower limit, as other shapes of load curves, assuming an identical energy consumption, would be linked to higher power values. Fig. 8/6 shows the comparison of areas relating to a rectangle and a triangle.

Therefore, a safety margin should be factored in when the power demand is determined from the annual energy consumption and the mean annual use period. This factor should reflect an approximated shape of the load curve.

Technical publications present different data for the annual use period reflecting differences in building characteristics and, of course, the data is subject to the framework conditions of the country under examination.

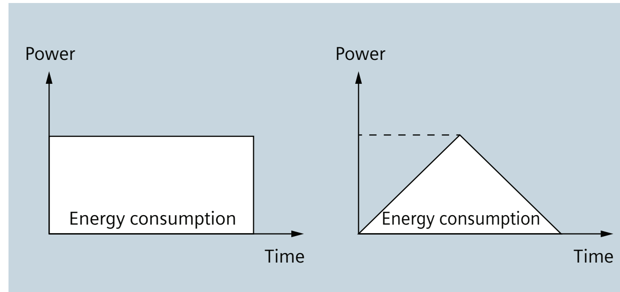


Fig. 8/6: **The comparison of rectangle area vs. triangle area illustrates the correlation between load curve shape and power demand**

Assuming a rectangular load curve, Tab. 8/1 and Tab. 8/2 will yield a tremendous range of values for the area-specific power demand:

Minimum energy consumption: 22 kWh/m^2 a
Maximum energy consumption: 358 kWh/m^2 a
Minimum annual use period: 1,000 h/a
Maximum annual use period: 5,000 h/a

Resulting in:

Minimum power demand: 4.4 W/m^2
Maximum power demand: 358 W/m^2

A factor 80 between the two extremes is certainly not realistic, which is also demonstrated in the bibliographical reference for the area-specific power demand in Tab. 8/3.

Country	Source	Annual use period in hours per annum	Features, type	Ref.
Germany	AMEV brochure no. 128	1,000 - 2,000	Small and medium-sized administrative buildings; one-shift operation	[8.17]
		3,500 - 5,000	Small and medium-sized administrative buildings; multi-shift operation	
		2,000 - 2,600	Large administrative buildings	
	Leitfaden elektrische Energie im Hochbau	2,750	Office building	[8.22]
	DIN 18559-10	2,750	Daytime: 2,543 h/a and nighttime: 207 h/a	
	Seminar papers City of Frankfurt	1,000	Administrative building, standard design	[8.23]
		1,800	Administrative buildings with advanced technical equipment	
Switzerland	Explanations for SIA 380/4	2,750	Use on 250 days for 11 hours	[8.24]
Hongkong	Statistical analysis of 120 office buildings	2,732	Type A: Modern and high quality	[8.25]
		2,645	Type B: Usual design and good quality	
		2,635	Type C: Simple basic construction	
U.S.A.	National Action Plan for Energy Efficiency	2,860	Scenario with 55 operating hours a week	[8.18]

Tab. 8/2: **Bibliographical reference for the annual use period of office and administrative buildings**

8

The majority of energy consumption values given in Tab. 8/1 is between 30 and 120 kWh/m^2a. Most data for the annual use period in Tab. 8/2 is in the range between 2,000 and 3,000 hours a year. These four values can be used to estimate more realistic power values:

Minimum power demand: 10 W/m^2

Maxmum power demand: 60 W/m^2

These values conform to the bulk of data given in Tab. 8/3.

Country	Source	Power demand in W per m^2 NFA	Features, type	Ref.
Germany	AMEV brochure no. 128	15 [1] (Range 5 - 25)	Administrative buildings with normal technical equipment	[8.17]
		20 [1] (Range 10 - 30)	Administrative buildings with high-standard technical equipment	
		23 [1] (Range 13 - 43)	Administrative building, normal equipment, as "passive house" with controlled room ventilation	
		26 [1] (Range 16 - 36)	Administrative building, partially air conditioned (15 %)	
		50 [1] (Range 40 - 60)	Administrative building, fully air conditioned	
Canada	Development in Toronto	39	Large office building; following [8.21], comparable with the conditions in Chicago	[8.26]
	Oxford Properties Group	34 - 49	Analysis of their own buildings, dependent on building size, building age and location	[8.27]
Italy	Energies 2013	24.9	Lighting and electrical appliances in a medium-sized office building	[8.19]
Austria	O.Ö. Energiesparverband Analysis of 1997	60 [1,2] (Range 15 - 95 [2])	7- 800 employees in the building 380 - 28,400 m^2 GFA Furnishing differences as to ventilation and air conditioning as well as data centre, kitchen and canteen	[8.5]
U.S.A.	National Action Plan for Energy Efficiency	52.7	Scenario - starting point Office tower area approx. 23,000 m^2	[8.18]
		50.3	Reduction by efficient office equipment (ENERGY STAR) and power management	
		50.1	Reduction by efficient lighting (e.g. LED and sensors with control)	
		37.8	Reduction by implementing all measures (using also smart building installations such as efficient motors, pumps, chillers)	
	Changes in Building Electricity Use	44.6	15-minutes measurements for office building in Martinez, U.S.A.	[8.20]
	Reference building US DoE	28 - 48	Small office building; different climate zones	[8.21]
		38 - 69	Medium-sized office building; different climate zones	
		30 - 37	Large office building; different climate zones	
UK	CIBSE Guide F	10 (GP [3]), 12 (typical)	Building "type 1": naturally ventilated, simple, often cellular offices; approx. 100 to 3,000 m^2 (treated floor area)	[8.10]
		12 (GP [3]), 14 (typical)	Building "type 2": naturally ventilated, open-plan offices with some cellular offices and special rooms; more amenities than with "type 1"; approx. 500 to 4,000 m^2 (treated floor area)	
		14 (GP [3]), 16 (typical)	Building "type 3": air conditioning, standard design; approx. 2,000 to 8,000 m^2 (treated floor area)	
		15 (GP [3]), 18 (typical)	Building "type 4": air conditioning, premium design; often company headquarter; high-class standard of amenities; approx. 4,000 to 20,000 m^2 (treated floor area)	

1) mean value
2) data for gross floor area multiplied by factor 1.1 (GFA = 1.1 * NFA)
3) GP: good practice, typical: typical for existing stock of office buildings (see Tab. 8/1)

Tab. 8/3: **Bibliographical reference for the area-specific power demand of office and administrative buildings**

8.2 Abbreviations

AMEV	Working Group of Mechanical and Electrical Engineering for State and Local Governments (Germany)
BCA	Building and Construction Authority (Singapore)
CBECS	Commercial building energy consumption survey
CHP	Co-generation of heat and power
CW	Calendar week
DIN	German Standardisation Institute
EC/EU	European Community / European Union
EEG	Renewable Energy Sources Act (Germany)
EEPL	Energy efficiency performance level
EEX	European Energy Exchange
EIA	Energy Information Administration
EMC	Electromagnetic compatibility
EN	European standard
EnEV	Energy Saving Ordinance
EnMS	Energy management system
ERP	Enterprise resource planning
ETU	Electronic trip unit
GFA	Gross floor area
HMI	Human machine interface
HVAC	Heating, ventilation, air conditioning
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratories
LED	Light emitting diode
MES	Manufacturing execution system
MID	Measuring Instruments Directive
NFA	Net floor area
ÖGUT	Austrian Association for Environment and Technology
ORNL	Oak Rich National Laboratories
PBP	Primary balancing power
PC	Personal computer
PV	Photovoltaics
RTU	Remote terminal unit
SBP	Secondary balancing power
SCADA	Supervisory Control and Data Acquisition
SEM	Sustainability and Energy Management
SFOE	Swiss Federal Office of Energy
TBP	Tertiary balancing power
TCP	Transmission Control Protocol (data networks)
TCP/IP	Transmission Control Protocol / Internet Protocol
TU	Technical University
UPS	Uninterruptible power supply
VDE	Association for Electrical, Electronic and Information Technologies (Germany)
VDI	Association of German Engineers

8.3 Formula symbols

Electrical energy	
W	Active energy in kWh
W_S	Apparent energy in kVAh
W_Q	Reactive energy in kvarh
$W_{max,¼ h}$	Maximum quarter-hourly active energy in kWh
W_{mean}	Energy consumption (per annum) in kWh
Electric power	
P	Active power in kW
$P_{max,¼ h}$	Maximum quarter-hourly active power in kW
P_V	Active power loss in kW
P_0	No-load power loss in kW
P_k	Short-circuit power loss in kW
P_{peak}	Maximum power demand in kW
k	Load factor of a transformer
η	Efficiency
S	Apparent power in kVA
S_r	Rated apparent power in kVA
S_N	Apparent power of neutral conductor in kVA
S_{Load}	Apparent power of load in kVA
Q	Reactive power in kvar
Current and voltage	
I	Current in A
I_{PE}	Protective earth conductor current in A
I_n	Neutral conductor current in A
I_r	Rated current in A
$I_{b, max}$	10-second value for the maximum operating current in A
$I_{b, mean}$	15-minute mean for the maximum operating current in A
I_{diff}	Residual current in A
U	Voltage in V
U_n	Nominal voltage in V
Phase factors and harmonics	
cos φ	Active power factor
λ	Power factor
THD_I	Harmonic current component
THD_U	Harmonic voltage component
t_{mean}	Annual use period (operating hours)

8

8.4 Bibliography

No.	Year	Published by / Authors / Series	Title
1.1	2015	JLL press release	"Büro-Nebenkosten steigen weiter - Die zweite Miete erreicht neuen Höchststand" (Incidental rental expenses for offices rising further - The 'second' rent reaches a new peak)
1.2	2010	Energie.Agentur NRW	Leitfaden Energieeffizienz für Krankenhäuser (Guide for the Energy Efficiency in Hospitals)
2.1	2010	M. Weiß; Siemens AG	Datenauswertung von Energiemanagementsystemen (Data Evaluation of Energy Management Systems)
2.2	2014	Siemens AG	Technical Series, Edition 11: The Energy Management Standard DIN EN ISO 50001
3.1	2014	Siemens AG	Technical Series, Edition 10: Liberalised Energy Market – Smart Grid, Micro Grid
3.2	2016	German Bundesrat	"EEG 2017 - Gesetz zur Einführung von Ausschreibungen für Strom aus erneuerbaren Energien und zu weiteren Änderungen des Rechts der erneuerbaren Energien - Drucksache 355/16" (EEG 2017 - Act on the Introduction of Tendering Procedures for Electricity gained from Renewables and on further Legal Changes concerning Renewables - Printed Matter 355/16)
3.3	2015	German Federal Ministry for Economic Affairs and Energy	An electricity market for Germany's energy transition (White Paper)
3.4	2015	www.juris.de (website of German legislation published on the Internet)	EEG 2014 - "Erneuerbare-Energien-Gesetz" (Renewable Energy Sources Act) of 21st July 2014 (German Federal Law Gazette 2014/Part I No. 1066) as amended by Section 15 of the Act of 29th August 2016 (Federal Law Gazette Part I No. 2034)
3.5	2015	German Federal Law Gazette 2015/Part I No. 55	Gesetz zur Neuregelung des Kraft-Wärme-Kopplungsgesetzes (KWK-G) (Act on the Revision of the Combined Heat and Power Act)
4.1	2016	Siemens AG	Technical Series, Edition 16: Transformer Selection according to Utilisation Profiles
7.1	2013	Siemens AG	Applications for Electric Power Distribution – Data Centres
8.1	2015	German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety	Publication of the rules for energy consumption characteristics and comparative values in the non-residential building stock
8.2	2014	VDI	VDI 3807: Characteristics consumption values for buildings - characteristics for heating energy, electricity and water
8.3	2012	City of Heidelberg, Office for Environmental Protection, Trade Supervision and Energy	Stromsparkonzept Heidelberg Bahnstadt (Electricity Saving Concept for the Heidelberg Urban Quarter of Bahnstadt)
8.4	2010	SFOE	Energy Consumption of Office Buildings and Large Distribution Boards
8.5	1997	Chamber of Trade and Industry in Upper Austria, Ökologische Betriebsberatung & O.Ö Energiesparverband	Energy parameters and savings potential for office buildings
8.6	2011	ÖGUT	Characteristic parameters of energy consumption in public service buildings
8.7	2013	LBNL, ORNL, Tsinghua University (China)	"LBNL-6640E: Building Energy Monitoring and Analysis"
8.8	2016	U.S. Energy Information Administration	CBECS 2012 survey data table C21
8.9	2015	enectiva	http://www.enectiva.cz/en/blog/2015/06/office-buildining-energy-insigts/ last visited on 22/07/2016
8.10	2004	CIBSE	CIBSE guide F (2nd edition): Energy efficiency in buildings
8.11	2014	iNSPiRe (EU-27 countries)	D2.1a - Survey on the energy needs and architectural features of the EU building stock

No.	Year	Published by / Authors / Series	Title
8.12	2008	L. Itard, F. Meijer - TU Delft	Towards a sustainable Northern European housing stock
8.13	2013	Statistics Norway	https://www.ssb.no/en/entjeneste/ (Data for 2011), last visited on 22/07/2016
8.14	2010	SINTEF Energy Research	State-of-the-art: Projects for estimating the electricity end-use demand
8.15	2014	BCA	BCA building energy benchmarking report 2014
8.16	2008	Intelligent Energy Europe (IEE)	EIE/05/144/SI2.419658; EL-TERTIARY; Monitoring Electricity Consumption in the Tertiary Sector
8.17	2015	AMEV	Brochure no. 128: Planung und Bau von Elektroanlagen in öffentlichen Gebäuden (Planning and Construction of electrical Installations in Public Buildings)
8.18	2007	U.S. National Action Plan for Energy Efficiency	http://www.iluvtrees.org/wp-content/uploads/2009/05/iltofficebuildingprofile.pdf last visited on 22/07/2016
8.19	2013	P. Caputo, C. Gaia, V. Zanotto in Energies 2013, 6, 6274-6292; doi:10.3390/en6126274	A Methodology for Defining Electricity Demand in Energy Simulations Referred to the Italian Context
8.20	2011	J. Mathieu, P. Price, S. Kiliccote, M. Piette in LBNL-4944E	Quantifying Changes in Building Electricity Use, with Application to Demand Response
8.21	2012	U.S. Department of Energy	"Commercial Reference Buildings" Data from http://energy.gov/eere/buildings/new-construction-commercial-reference-buildings
8.22	2000	Hessian Ministry for Environment, Agriculture and Forestry	Leitfaden elektrische Energie im Hochbau (Guide for Electrical Energy in Building Construction)
8.23	2015	City of Frankfurt	Seminar Programme for Energy Officers Part 3: Saving electricity
8.24	1996	SIA	Guideline for applying SIA 380/4 Recommendation: Elektrische Energie im Hochbau (Electrical Energy in Building Construction)
8.25	2013	W. Chung, University of Hong Kong	A study of electricity use performance of Hong Kong office tenants (at 2013 World Congress ANBRE13 in Seoul)
8.26	2012	T. Beck, C. Jattan-Iogna, D. Nan, J. St. Paul Butler; University of Toronto	The Power to Grow: The Economic and Fiscal Benefits of Urban Development Facilitated by Local Generation and Conservation within a Constrained Grid
8.27	2009	Oxford Properties Group	Sustainable Intelligence - Operations guide for office buildings
8.28	2016	Siemens AG	Planning of Electrical Power Distribution - Technical Principles

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