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Energy efficiency in the planning of low-voltage installations

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1. Introduction

Since the 1980s, energy efficiency has been regarded as an important leverage for the turnaround in energy policy and for avoiding CO_2 emissions. In the European Directive 2012/27/EU [1] on energy efficiency, the European Parliament and the Council determined that the requirement set up by the EU Commission in 2007 [2] shall be attained. This requirement stipulates a reduction of CO_2 emissions by 20 % in Europe – referred to forecasts made for 2020.

Improving energy efficiency by 20% in Europe contributes significantly to achieving this goal (Fig. 1). The development of energy efficiency within the European Union shall be measured through the reduction of primary energy consumption by 14 % until 2020 (compared to 2005) [3]. Gross electricity consumption in Germany shall be diminished by 10 % between 2008 and 2020 [4]. As a side effect of improved energy efficiency, it is expected that that concerns regarding a rise in energy cost and a deterioration of supply reliability will decrease.

To include this approach in technical standards for products, systems, and installations, more and more standards, directives and regulations are being adapted in terms of energy efficiency or introduced anew. Degrees of efficiency and system-inherent losses reflect the state of the art in product development, for example. Installation requirements as to energy-efficient operation can already be set up and considered during the planning phase of electrical installations.

Planners must pay attention to optimal energy utilisation when dimensioning installations, and they must include the requirements set up by the customer, the end users, the distribution grid operators and the electrical utility company in their considerations. Corresponding requirements and recommendations for the energy efficiency of low-voltage electrical installations in buildings and systems are described in IEC 60364-8-1 (in Germany: VDE 0100-801).

The energy-efficient design and layout of power distribution systems is a challenging task, where expenses are lowest during the planning phase, as cables, busbars and transformers cannot easily be replaced during operation. On the one hand, the cost of installation is extremely high, and on the other hand, the electrical installation needs to be isolated for the purpose of component replacement. In most cases, retrofitting or converting is not worth the financial expense. Expenses are lower if efficiency criteria, as described in the above standard, are considered as early as in the planning stage. Besides loads, the IEC 60364-8-1 (VDE 100-801) standard also deals with transformers, cables, busbars, and the use of metrology.

After its erection, the electrical installation shall produce as few losses as possible and metrology shall ensure continuous transparency in terms of efficiency.

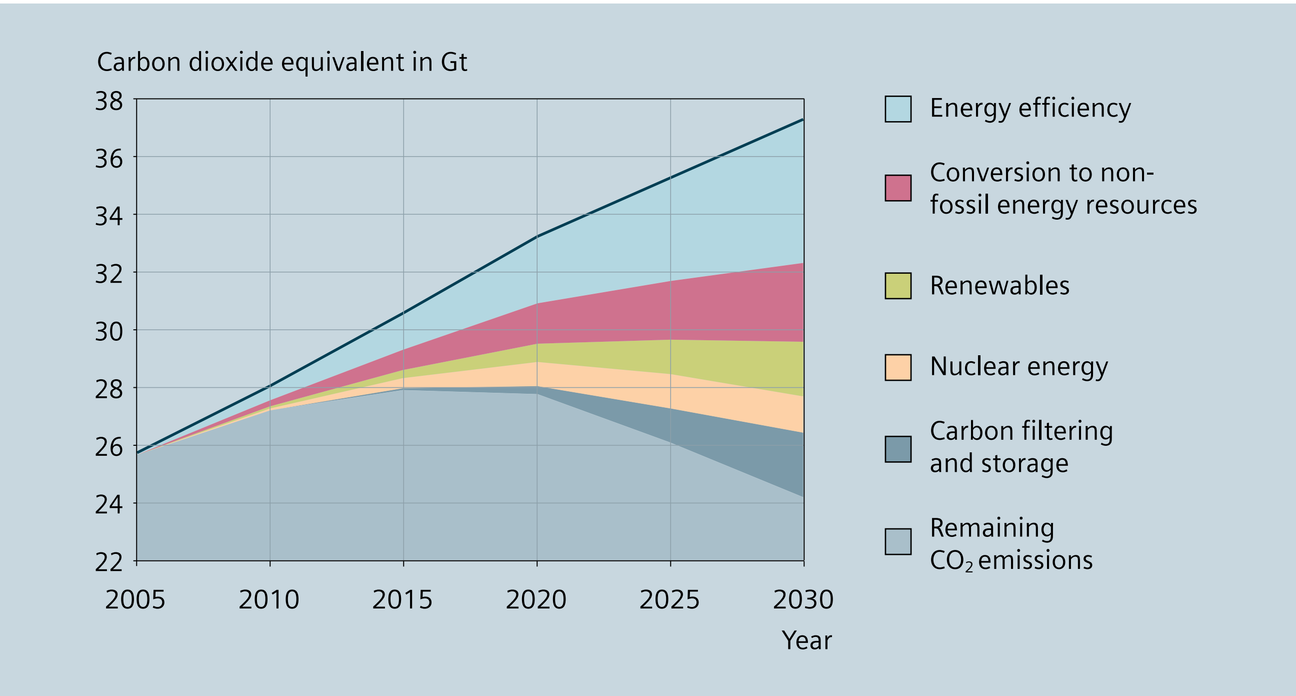


Fig. 1: **Methods for reducing worldwide CO_2 emissions [2]**

2. The framework of IEC 60364-8-1 (VDE 0100-801):

The scope of the standard includes

- residential buildings
- commercial buildings
- industrial buildings
- infrastructure facilities

The rule for efficiency-increasing measures is that they neither impair availability and supply nor operation of systems, buildings or facilities, to prevent that the installation would no longer meet user requirements if so. In addition, users should have the choice between energy-optimised operation and default operation, or even operation under exceptional circumstances. Consequences resulting from the user's choice must be transparent.

The aim is efficient electric power distribution yielding the best possible result and minimal losses for the specific application. Here, the focus is not on the technically optimal approach but on the aspect of the optimal cost-performance ratio. To verify efficiency during operation, measurement procedures are described which can be employed throughout the entire building life, even in cases of changing usage. Meeting the requirements of this standard creates the prerequisite for compliance with ISO 50001 (Energy management systems – Requirements with guidance for use) (see Fig. 2).

Subaspects of energy classification in terms of installation profile, installation efficiency and performance level (see section 3), which are generally to be considered in planning according to IEC 60364-8-1 (VDE 0100-801), are as follows:

- Determination of the load profile
- Best possible layout of the main substation in terms of the load centres
- Optimisation analyses for important components such as
  - motors
  - lighting
  - HVAC (heating, ventilation, air conditioning)
  - transformers
  - wiring systems
  - reactive power compensation
- Specifications for measuring systems
  - power factor measurement
  - energy and power measurements
  - voltage measurement
  - harmonics and and interharmonic component
- Requirements placed on renewable sources of energy
- Requirements in terms of efficiency performance
  - distribution of the annual consumption
  - power factor
  - transformer efficiency

Note: The separate aspects of "efficiency of local storage" and of "efficiency of local generation" are currently being prepared for IEC 60364-8-1 (VDE 0100-801).

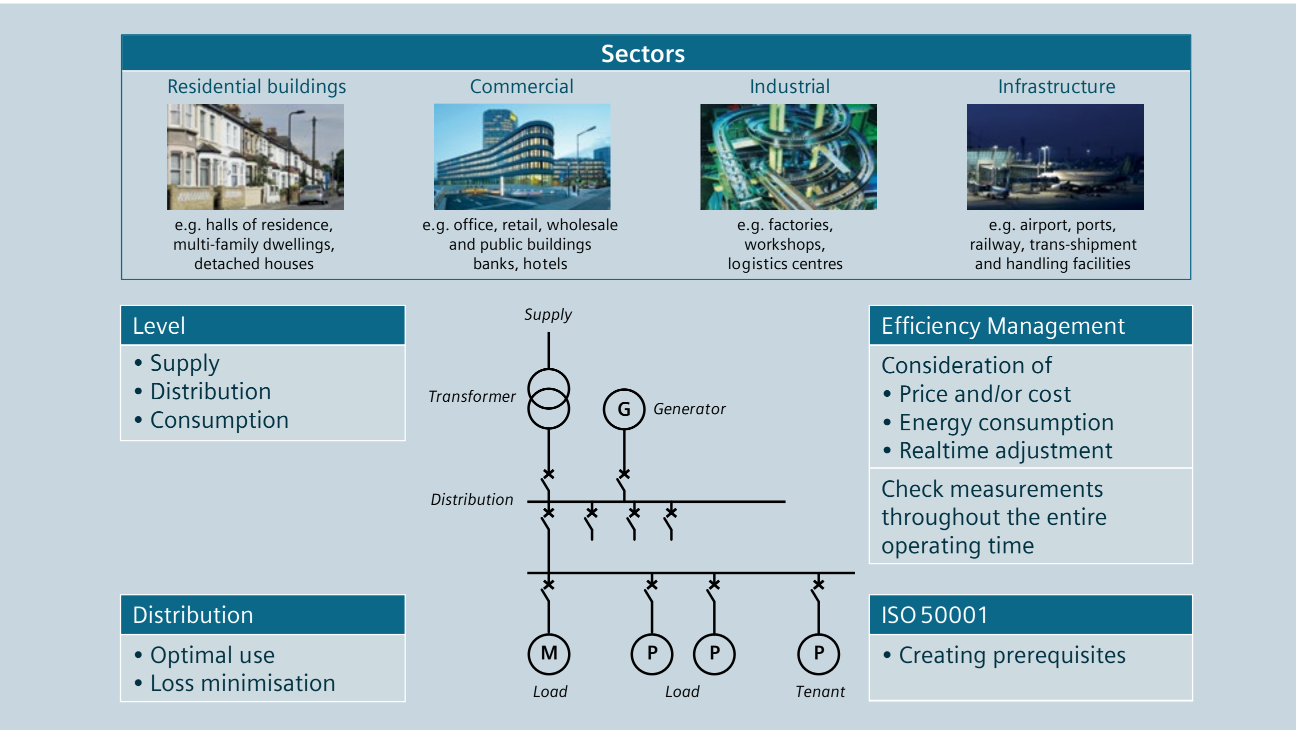


Fig. 2: **Measured values and characteristic parameters at the different distribution levels**

3. Electrical installation efficiency classes (EIEC)

To classify installation efficiency, the above-mentioned subaspects are categorised according to evaluation criteria and rated with points. Criteria grading from 0 to 4 corresponds to the allocation of points “0 to 4” (see Tab. 1). Subaspects are distinguished according to efficiency measures (EM) and energy efficiency performance levels (EEPL).

In total, the maximum score is:

16 subaspects • 4 points = 64 points

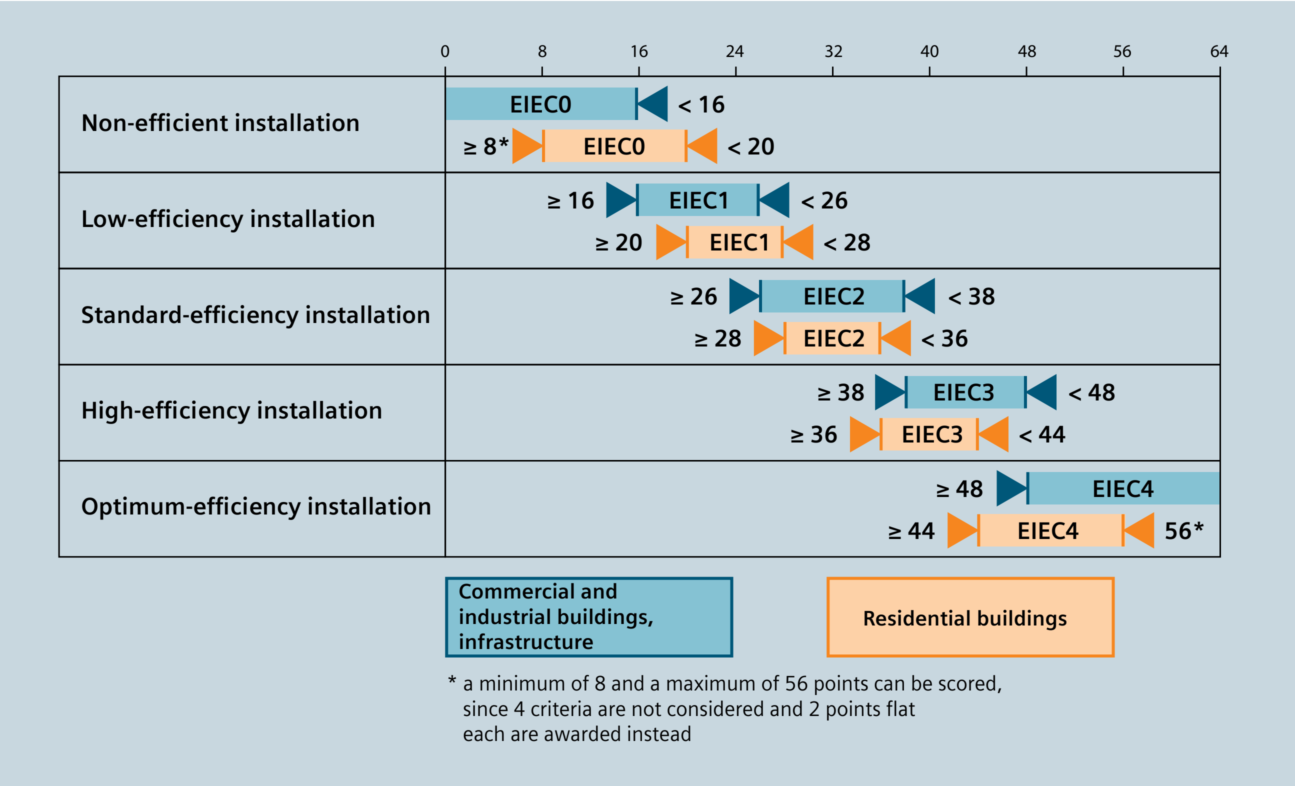
The point scale for the five electrical installation efficiency classes (EIEC) EIEC0 to EIEC4 is shown in Tab. 2. The rating structure is different for residential buildings, since four of the subaspects (power factor measurement, measurement of harmonics, distribution of annual consumption, and reduction of reactive power) are not considered. With residential buildings, these four criteria are rated by an average value of 2 points flat each.

Note:
On account of the fixed rating of these four subaspects for residential buildings, the value ranges for residential and non-residential buildings (commercial buildings, industrial buildings, infrastructure facilities) differ.

Evaluation categories	Enumeration acc. to Annex B of IEC 60364-8-1 (VDE 100-801)	Evaluation criteria	Valuation standards
Energy efficiency measures (EM)	B.1	Determination of the load profile	Load profile recording of consumption for different periods
	B.2	Layout of the main supply	Comparison of the planned location of the main feeder with a calculated optimum
	B.3	Optimisation analysis for motors	Analysis and optimisation of the performance classes of motors and drives - as a relation between installed capacity total and the sum of all motors and drives planned
	B.4	Optimisation analysis for lighting	Assessment of lamp type and position as well as lighting control, also in terms of natural light conditions
	B.5	Optimisation analysis for heating, ventilation, air conditioning	Temperature control and subdivision into zones
	B.6	Optimisation analysis for transformers	Cost estimate of investment and loss over entire transformer life
	B.7	Optimisation analysis for wiring systems	Optimisations for load centre, voltage drop, cross sections, harmonics and/or circuit subdivision into meshes have been performed
	B.8	Optimisation analysis for reactive power compensation	The maximum reactive power value is defined; central, zonal or individual reactive power values are established
	B.9	Requirements of measuring the power factor	Temporary or permanent measurement and measurement location
	B.10	Requirements of measuring electric energy and power	Measurements are taken centrally, for each zone, each application and/or mesh-related
	B.11	Requirements of voltage measurement	Periodic or permanent measurement in the main distribution board, main switchboard, distribution boards and/or at major loads
	B.12	Requirements of measuring harmonics	Occasional, periodic, or permanent measurement of summated values or of the detailed harmonic spectrum *
	B.13	Requirements for renewable energy	To be considered or installed, where the proportion of renewables referred to the total installed power is considered in addition
Energy efficiency performance levels (EEPL)	B.14	Minimum requirements for distribution of annual consumption	Degree of further breaking down the division of annual consumption into applications and additionally into zones *
	B.15	Requirements for reducing reactive power compensation	Power factor steps *: No consideration > 0.85; > 0.90; > 0.93; > 0.95
	B.16	Requirements of transformer efficiency	Transformer efficiency levels *: No consideration; > 95 %; > 97 %; > 98 %; > 99 %

* These subaspects are not considered for residential buildings. They are always rated with two points each in the evaluation.

Tab. 1: **Subaspects and energy efficiency evaluations of an installation in compliance with IEC 60364-8-1 (VDE 0100-801):**



Tab. 2: **Evaluation scales for the electrical installation efficiency classes for use in planning. Values for classification according to IEC 60364-8-1 (VDE 0100-801) were altered following the description given in this publication.**

Attention!
The points scheme given in Table B.19 of the informative Annex B of the IEC 60364-8-1 (VDE 0100-801) standard (see Tab. 3) specifies no lower limits for the individual efficiency classes (possibly erroneously). This means probably that the lower limit of one class is the upper limit of the lower-level class.

Mathematically speaking, all installations where the score is less than 50 (for residential buildings) or less than 58 (for commercial and industrial buildings and infrastructure facilities) would be planned with optimal efficiency according to the standard. The standard leaves open, however, what to call a planning concept which attains or exceeds 50 and 58 points, respectively.

The fact that the limit values between EIEC2 and EIEC3 are identical for residential and non-residential buildings does not seem logical either, since an average rating for residential and non-residential buildings is 32 points (16 • 2 points). A wider range from 26 to 38 points would be logical to indicate standard efficiency of non-residential buildings. For residential buildings, 8 points always mean a step up or down in efficiency class. For this reason, Tab. 2 show a possible points scale which is oriented towards the standard, but is structured more logically. Tab. 3 lists the actual values from the IEC 60364-8-1 (VDE 0100-801) standard.

Electrical installation efficiency classes (EIEC)	Residential buildings	Non-residential buildings
EIEC0	< 20 points	< 16 points
EIEC1	< 26 points	< 28 points
EIEC2	< 36 points	< 36 points
EIEC3	< 44 points	< 48 points
EIEC4	< 50 points	< 58 points

Tab. 3: **Rating scheme for the electrical installation efficiency classes in compliance with IEC 60364-8-1 (VDE 0100-801)**

4. Specific measures for improving efficiency

As efficiency evaluation normally requires knowing individual product characteristics, the standard uses the analysis possibilities required therein as evaluation criteria for the energy efficiency measures (EM). Specific values are given for level 1 to 4 of the energy efficiency performance levels (EEPL). If these values have not been considered, the performance level is EEPL0.

HVAC optimisation analyses, analyses of reactive power compensation and requirements for measuring electrical energy and power use the terms “application”, “mesh” and “zone” (see Tab. 1 and Fig. 3).

Typical “applications” are lighting, heating, moving walkways, printers, ... A “mesh” identifies one or more electric circuits in the installation. A circuit can only belong to one “mesh”. A “zone” is defined as an area or surface which defines part of an installation such as a room or a floor or a production hall. A “mesh” can extend over one or more than one “zones” (Fig. 3).

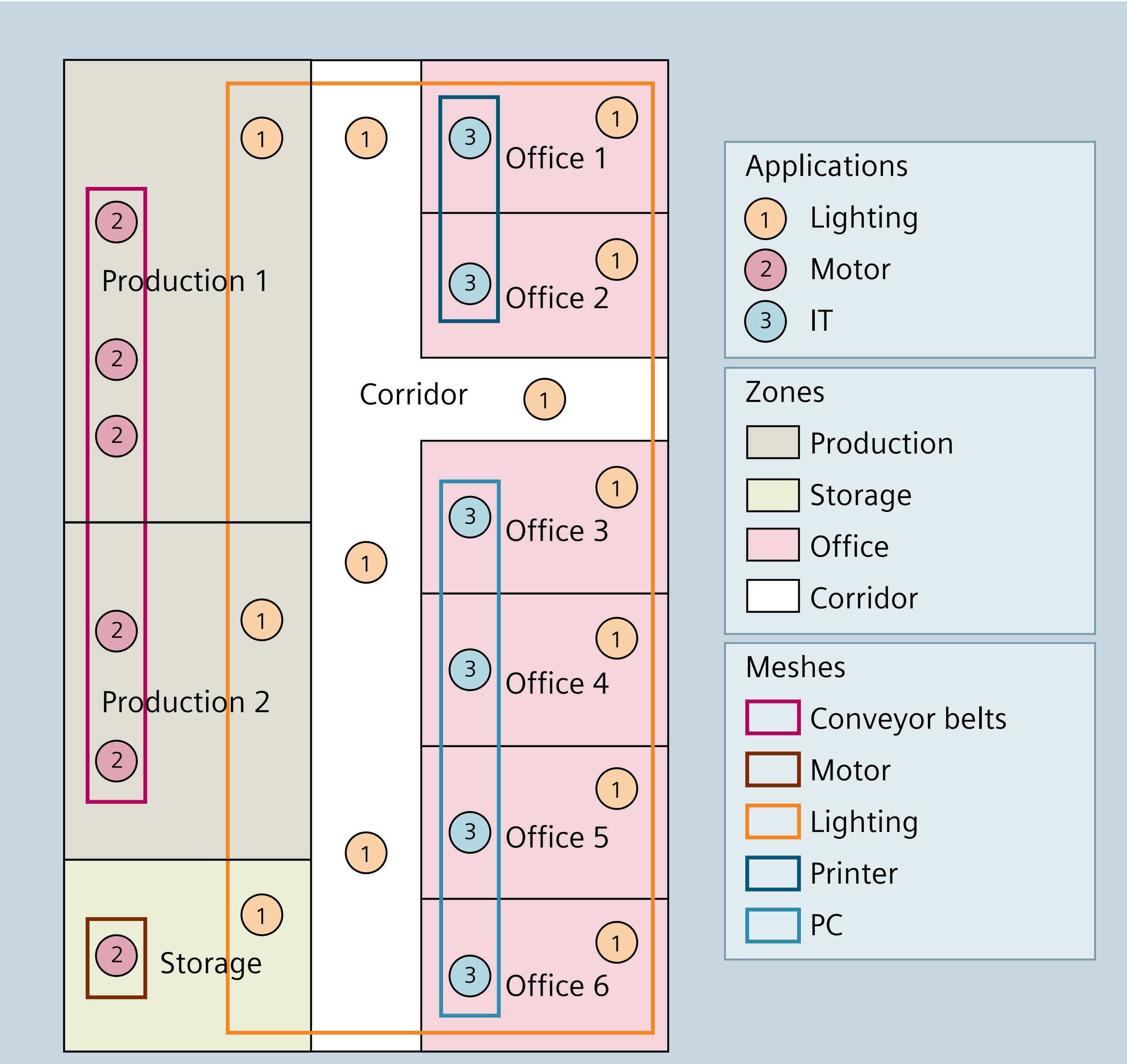


Fig. 3: **Examples of meshes and zones in energy efficiency evaluations**

4.1 Load profiles

Load profiles (subaspect B.1 in IEC 60364-8-1; VDE 0100-801) document the imported energy over the period considered. They indicate the consumption pattern at the measurement point. The standard requires documentation at the feed-in to the installation (point of supply from the distribution system).

If the annual consumption of an installation is above 100,000 kWh per annum, the metering operator must install a load meter which measures the energy imported in quarter-hourly intervals. Upon request the metering operator will forward these measured values. In case of consumption amounting to less than 100,000 kWh/a, consumers must provide for data acquisition and recording themselves.

The implementation of the standard is problematic, since performance criteria are specified here which will only become relevant when the installation goes live (exception: "permanent measurement"). In the context of installation planning, provision of appropriate facilities and documentation means should be assessed.

4.2 Location of the main substation

To keep losses within the power distribution system as low as possible, the main feeder should be located as close to the load centres as possible. The alternative featuring greater cable diameters and wider cable spacing is usually less efficient in economic terms. Local conditions, however, play an important part here.

The simple calculation model proposed in the standard (barycentre method, informative Annex A) is based on the spacing between the main feeder and the individual applications as well as their assumed annual energy consumption. The distance between the calculated, spatial load centre - weighted according to energy consumption - and the most distant load is compared with the distance between the intended location of the main feeder and the most distant load, and findings are evaluated.

4.3 Motors

Following IEC 60034-30-1 (VDE 0530-30-1), mains-supplied three-phase motors are rated according to their international energy efficiency class (IE code):

- IE1 Standard efficiency
- IE2 High efficiency
- IE3 Premium efficiency
- IE4 Super premium efficiency

In the future, an additional IE5 class shall be introduced in the standard, characterised by 20 % lower losses compared to IE4.

According to the eco-design requirements given in Regulation (EC) No 640/2009 [5], motors (7.5 to 375 kW) may only be distributed within the European Union as of the beginning of 2015 which conform to class IE3 (or IE2 with speed control). As of January 1, 2017 this will also apply to smaller motors of a 0.75 kW to 7.5 kW rating.

Although IEC 60364-8-1 (VDE 0100-801) includes a reference to the IEC 60034-30 series, an IE code requirement has not been specified. The measure for assessment is the proportion of motors – referred to the total installed motor capacity –which has been analysed in terms of efficiency performance level during planning and will be optimised. When new motors are considered in planning, the IEC 60364-8-1 (VDE 0100-801) requirement is 100 % fulfilled for the category "motors", because regulation (EC) 640/2009 takes effect.

4.4 Lighting

Lighting systems do not require a detailed planning of energy efficiency for evaluation. The following is evaluated:

- "Considerations" of the lamp type and position
- "Considerations" of the relation between lamp type/position and natural light
- Existence of lighting control corresponding to
  - the natural source of light or building application or lamp type
  - the natural source of light and building application and lamp type

4.5 Heating, ventilation, air conditioning (HVAC)

For the purpose of an HVAC optimisation analysis, the type of control/adjustment (time, temperature, sensor-controlled) and the zonal subdivision of the control system are evaluated. Rightly, no more values for maximum energy consumption or energy quantities per annum are required beyond this, since dependencies of climatic conditions, desired levels of convenience, construction measures and further particularities would play a key role in this context. Generally, this planning criterion cannot be directly influenced by the electrical designer in most cases. Integrated planning thus lays the best foundation for energy-efficient planning.

4.6 Transformers

Following IEC 60364-8-1 (VDE 0100-801), type and efficiency should be given the most attention when selecting a transformer. For the purpose of an efficiency evaluation during the planning phase, an optimisation analysis (B.6) can be made considering cost of investment and cost of consumption caused by losses for the transformer life.

In IEC 60364-8-1 (VDE 0100-801), a second evaluation of transformers (B.16) specifically considers the concrete efficiency value. Owing to Regulation (EU) No 548/2014 [6] of the European Union, oil-immersed distribution transformers in the EU attain at least the rating level 3 (3 points for a transformer efficiency of > 98 %). Oil-immersed transformers with a power rating of 100 kVA and higher even have an efficiency greater than 99 %, thus attaining rating level 4. Cast-resin distribution transformers with 630 kVA and higher also demonstrate an efficiency better than 99 %. And cast-resin transformers between 100 and 400 kVA attain rating level 3 with an efficiency of more than 98 %.

4.7 Wiring systems

Avoiding losses caused by cables and wiring is here the main concern of an efficiency evaluation. Therefore, the lengths and diameters of cables and wiring, the impact of harmonics caused by loads, as well as material properties and ambient conditions must be given attention in the planning. The SIMARIS design planning tool supports the planner in the calculation of the voltage drop in consideration of the above parameters.

In order to attain the best rating, the planner must demonstrate that he has included the load centre, cable and wiring losses, creation of meshes as a basis for metrological data capture, documentation and evaluation of characteristics as well as the associated control system into his considerations.

Attention!
The German version, VDE 0100-801:2015-10, of this standard links the methods given in Table B.7 of the optimisation analysis by the conjunction "or" always, thus they are permitted as alternatives for optimal rating. This is only correct for EM1. For EM2 (6.3 and 6.7) and EM4 (6.3, 6.7 and 7.3) the conjunction "and" should be used here as in IEC 60364-8-1.

4.8 Reactive power

Evaluation of the installed reactive power firstly includes an optimisation analysis and secondly the active power factor established in the planning. For the purpose of the optimisation analysis in the planning phase, it is graded to which extent the reactive power value is defined or - even better - central, zonal and/or individual components are considered.

To optimise reactive power of non-residential buildings, it is assessed which minimum value is attained for the active power factor in the planning phase (ranging from > 0.85 to > 0.95 inductive). The standard does not deal with capacitive loads, which are, however, increasingly present in applications. Evaluations performed in operation (e.g. for analyses based on ISO 50001) require measured data of active and reactive power.

It should be noted that the "Technical Supply Conditions" of grid operators in Germany often define an active power factor requirement of 0.92 and better.

4.9 Measurements of power factor, voltage and harmonics

These are the evaluation criteria given in the standard: Power factor, voltage and harmonics (current and voltage components of the harmonic THD_I and THD_U as well as interharmonic components). Measurements may be taken occasionally, periodically, or permanently, and are evaluated accordingly. In addition, the measuring arrangement in the main distribution system, in the main switchboard, distribution boards and for major loads (power factor and voltage), and at the "origin of the installation" and at the main substation (harmonics) respectively, is rated. Harmonics are not considered in the context of residential buildings.

Unfortunately, the documentation and data archiving is given no explicit attention. To cater for this, planning would have to provide for permanent data acquisition.

Attention!
As harmonics have an influence on losses and efficiency, the standard uses the power factor λ and not the active power factor $\cos \varphi$.

4.10 Measurements of energy and power

The measuring arrangement and measurement interlinking is factored in as an evaluation criterion: Measurement of large equipment, per zone, per mesh and for each application. As zones generally do not correlate with the electrical distribution, a measurement by zone requires interlinking of several measurements, using software if necessary. This helps to plan application- and mesh-related measurements more easily.

The time dependency of power demand and consumption (summer – winter, day – night, workday – bank holiday, ...) is stated in the standard, but it is not reflected in the evaluation categories for energy and power measurements.

Another evaluation criterion is the knowledge of the distribution of annual consumption (presumably the annual energy consumption), which must already be assessed in the planning phase. The underlying intention is to attain a most comprehensive allocation of annual consumption to individual applications and spatially to zones as well. The percentages to be used for evaluation refer to annual consumption values which can be allocated to individual load items of applications and to zones by means of planning the measuring equipment to be installed. The percentage rises from 80 % (1 point) to 99 % (4 points). This requirement is not considered for residential buildings.

4.11 Use of renewable sources of energy

The assessment of planning concepts for the use of renewable energy sources ranges from simple consideration to an installation without power specification and extends to the planning of an installation where up to 10 % of the installed capacity can be supplied by renewables.

5. Conclusion

In order to plan installations to be erected in compliance with the IEC 60364 (VDE 0100) standard series according to customer and contract specifications, it will be necessary in the future to evaluate the efficiency of an electric power distribution system as early as in the planning phase. Their future operation must also be considered.

For the purpose of planning, the contract awarding authority and the planner should reach an understanding as to the required electrical installation efficiency class in compliance with IEC 60364-8-1 (VDE 0100-801). The requirement of standard conformity alone (without specifying a certain class) can also be met by an evaluation result of zero points.

Efficiency classes shall help making planning quality comparable. The choice of considering higher-quality design variants for the individual subaspects in the planning concept may result in a cost increase for the erection of the installation. But the improved transparency gained should help reduce costs in operation so that efficiency considerations will yield a total cost benefit over the installation's service life. Accordingly, efficiency improvement contributes to CO_2 reduction. Moreover, the evaluation of installation efficiency in accordance with IEC 60364-8-1 (VDE 0100-801) can be integrated into an energy management system compliant with ISO 50001.

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Siemens AG

Energy Management
Medium Voltage & Systems

Mozartstr. 31c
91052 Erlangen

Germany

E-mail: consultant-support.tip@siemens.com

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