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Report

Preparatory Studies for Product Group in the Ecodesign Working Plan 2012-2014:

Lot 8 - Power Cables

Task 1 report – Scope (definitions, standards and legislation) (3th version)

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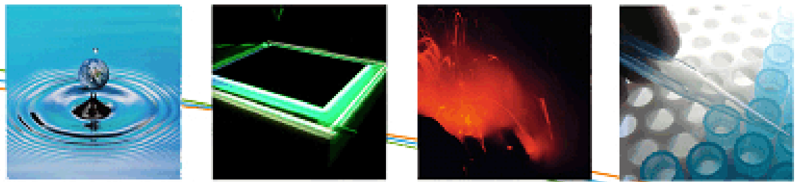

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Executive Summary

VITO is performing the preparatory study for the new upcoming eco-design directive for Energy-related Products (ErP) related to power cables, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/index_en.htm).

In order to improve the efficient use of resources and reduce the environmental impacts of energy-related products the European Parliament and the Council have adopted Directive 2009/125/EC (recast of Directive 2005/32/EC) establishing a framework for setting Ecodesign requirements (e.g. energy efficiency) for energy-related products in the residential, tertiary, and industrial sectors. It prevents disparate national legislations on the environmental performance of these products from becoming obstacles to the intra-EU trade. Moreover the Directive contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, taking into account the whole life cycle cost. This should benefit both businesses and consumers, by enhancing product quality and environmental protection and by facilitating free movement of goods across the EU. It is also possible to introduce binding information requirements for components and sub-assemblies.

The MEErP methodology (Methodology for the Eco-design of Energy-Related Products) allows the evaluation of whether and to which extent various energy-related products fulfil the criteria established by the ErP Directive for which implementing measures might be considered. The MEErP model translates product specific information, covering all stages of the life of the product, into environmental impacts (more info http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm).

The tasks in the MEErP entail:
Task 1 - Scope (definitions, standards and legislation);
Task 2 – Markets (volumes and prices);
Task 3 – Users (product demand side);
Task 4 - Technologies (product supply side, includes both BAT and BNAT);
Task 5 – Environment & Economics (Base case LCA & LCC);
Task 6 – Design options;
Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis).
Tasks 1 to 4 can be performed in parallel, whereas 5, 6 and 7 are sequential.
Task 0 or a Quick-scan is optional to Task 1 for the case of large or inhomogeneous product groups, where it is recommended to carry out a first product screening. The objective is to re-group or narrow the product scope, as appropriate from an ecodesign point of view, for the subsequent analysis in tasks 2-7.

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1 List of Acronyms

A	Ampere
AC	Alternating Current
Al	Aluminium
AREI	Algemeen Reglement op de Elektrische Installaties
ASTM	American Society for Testing and Materials
ATEX	ATmosphères EXplosibles
avg	Average
B2B	Business–to-business
BAT	Best Available Technology
BAU	Business As Usual
BNAT	Best Not yet Available Technology
BS	British Standard
CE	Conformité Européenne
CEN	European Committee for Normalisation
CENELEC	European Committee for Electro technical Standardization
CPD	Construction Products Directive
CPR	Construction Products Regulation
CSA	Conductor Cross-Sectional Area (symbol: S)
Cu	Copper
Cu-ETP	Copper- Electrolytic Tough Pitch
Cu-OF	Copper – Oxygen Free
CO_2	Carbon Dioxide
DALI	Digital Addressable Lighting Interface
DC	Direct Current
DIN	Deutsches Institut für Normung
E	Energy
EC	European Commission
EEE	Electrical and Electronic Equipment
EMC	Electro Magnetic Compatibility
EMI	Electromagnetic Interference
EMS	Energy Management System
EN	European Norm
EOL	End Of Life
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
EPR	Ethylene Propylene Rubber
ErP	Energy related Products
EuP	Energy using Products
EU	European Union
HD	Harmonization Document
HV	High Voltage
Hz	Hertz
I	Current
IACS	International Annealed Copper Standard
Iav	Average Current
IEC	The International Electro technical Commission
IEV	International Electrotechnical Vocabulary
INDL	INDustry Level
IT	Information Technology
k	kilo (10^3)
kg	Kilogram
Kd	Distribution factor

Kf	Load form factor
Kt	Temperature correction factor
kWh	KiloWatt hour
L	Length
LCA	Life Cycle Assessment
LF	Load Factor
LV	Low Voltage
LVD	Low Voltage Directive
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy using Products
MS	Mega Siemens
MV	Medium Voltage
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne - Statistical classification of economic activities in the European Community
NBN	Bureau voor Normalisatie - Bureau de Normalisation
NEN	NEderlandse Norm
NF	Norm France
P	Power
PE	Polyethylene
PEP	Product Environmental Profile
PF	Power factor
PJ	Peta Joule
PP	Polypropylene
PRODCOM	PRODuction COMmunautaire
PV	PhotoVoltaic
PVC	Polyvinylchloride
R	Resistance
R20	Resistance at 20°C
RCD	Residual Current Device
REMODECE	Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe
RES	Renewable Energy Sources
r.m.s	Root Mean Square
RoHS	Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
S’	Apparent power
S	Nominal cross sectional area of a conductor
SERL	SERvices Level
SME	Small and Medium sized Enterprise
TBC	To Be Completed
TBD	To Be Defined
TC	Technical Committee
TR	Technical Report
TWh	Terra Watthour
UK	United Kingdom
V	Volt
VA	Volt Ampere
VDE	Verband der Elektrotechnik und Elektronik
VITO	Flemish institute for Technological Research
W	Watt
WEEE	Waste Electrical and Electronic Equipment
XLPE	Cross-linked Polyethene
XLPVC	Cross-linked PVC

Use of text background colours

Blue: draft text
Yellow: text requires attention to be commented
Green: text changed in the last update

CHAPTER 1 TASK 1 - SCOPE

Objective: This task classifies and defines the energy-related product group power cables and sets the scene for the rest of the tasks. The product classification and definition should be relevant from a technical, functional, economic and environmental point of view, so that it can be used as a basis for the whole study.
It is important to define the products as placed on the Community market. This task consists of categorization of power cables according to Prodcom categories (used in Eurostat) and to other schemes (e.g. EN standards), description of relevant definitions and of the overlaps with the Prodcom classification categories, scope definition, and identification of key parameters for the selection of relevant products to perform detailed analysis and assessment during the next steps of the study. This task will also classify power cables into appropriate product categories while providing a first screening or quick-scan of the volume of sales and stock and environmental impact for these products.
Further, harmonized test standards and additional sector-specific procedures for product-testing will be identified and discussed, covering the test protocols for:

- Primary and secondary functional performance parameters (Functional Unit);
- Resource use (energy, etc.) during product-life;
- Safety (electricity, EMC, stability of the product, etc.);
- Other product specific test procedures.

Finally, this task will identify existing legislations, voluntary agreements, and labelling initiatives at the EU level, in the Member States, and in the countries outside the EU.

Summary of Task 1:

In brief the scope of the study is: **’losses in installed power cables in buildings’**, the power cable being the product put into service by the electrical installer in a circuit of an electrical installation in a building. The electrical installation itself is considered as its system environment and/or the extended product scope, meaning that it will be analysed at the level needed related to cable losses.

The electrical installation is taken into account as a system. In this context the proposed primary functional performance parameter is **’current-carrying capacity’**.

Losses in installed power cables in buildings are directly related to the loading. Therefore **nine functional categories** of cable circuits were defined, i.e. ’lighting’, ’socket-outlet’ and ’dedicated’ circuits in the ‘residential’, the ‘services’ and the ‘industry’ **sector.**

A first screening estimated losses in the services and industry sector about 2% while losses in the residential sector seems to be much lower (<0.3%). This is because circuits in residential buildings are in general much shorter and have relative low loading. Therefore it is proposed to focus in the subsequent tasks on the services and industry sector circuits.

Relevant standards, definitions, regulations, voluntary agreements and commercial agreements on EU, MS and 3rd country level are part of this task report. Important secondary performance parameters are the ‘Nominal Cross-Sectional Area (CSA)’ and its corresponding ‘maximum DC resistance at 20°C (R20)’, which are defined in standard IEC 60228. For the performance electrical installation codes play an important role and they can differ per member state.

1.1 Product Scope

1.1.1 Key methodological issues related to the product scope definition

In this task the classification and definition of the products should be based notably on the following categorizations:

- Prodcom category or categories (Eurostat);
- Categories according to EN- or ISO-standard(s);
- Other product-specific categories (e.g. labelling, sector-specific categories), if not defined by the above.

Prodcom should be the first basis for defining the products, since Prodcom allows for precise and reliable calculation of trade and sales volumes (Task 2).
If the proposed product classification and definition relevant from a technical, economic and environmental point of view does not match directly with one or several Prodcom categories, the study should detail how the proposed product categories are mapped to the Prodcom categories or the other categories mentioned above.

In particular customer-made products, business-to-business (B2B) products or systems incorporating several products may not match with Prodcom categories. In these cases, the standalone or packaged products placed on the European internal market, to which a CE mark is/could be affixed, should be defined. This may result in several Prodcom or otherwise categorised products relevant for power cables.

The above existing categorizations are a starting point for classifying and defining the products and can be completed or refined by other relevant criteria, according notably to the functionality of the product, its environmental characteristics and the structure of the market where the product is placed. In particular, the classification and definition of the products should be linked to the assessment of the primary product performance parameter (the "functional unit").

If needed, a further segmentation can be applied on the basis of secondary product performance parameters. This segmentation is based on functional performance characteristics, and not on technology.

Where relevant, a description of the energy systems affected by the energy-related products will be included, as this may influence the definition of the proposed product scope.

The resulting product classification and definition should be confirmed by a first screening of the volume of sales and trade, environmental impact and potential for improvement of the products as referred to in Article 15 of the Ecodesign Directive.
Also information on standards, regulations, voluntary agreements and commercial agreements on EU, MS and 3rd country level should be considered when defining the product(s) (section 1.3.1).

1.1.1.1 Important definitions and terminology in electrical installations

Important definitions and terminology in electrical installations (IEC 60050, IEC Electropedia Area 461) are:

- Low Voltage (IEV 601-01-26 / Fr: basse tension / De: Niederspannung): a set of voltage levels used for the distribution of electricity and whose upper limit is generally accepted to be 1 000 V a.c;

- Electrical installation (IEV 826-10-01 / Fr: installation électrique / De: elektrische Anlage): assembly of associated electric equipment having co-ordinated characteristics to fulfil specific purposes;

- (Electric) circuit (of an electrical installation) (IEV 826-14-01 / Fr: circuit (électrique) (d'installation électrique) / De: Stromkreis (einer elektrischen Anlage)): assembly of electric equipment of the electrical installation protected against overcurrents by the same protective device(s);

- Cable (IEV 151-12-38 / Fr: cable / De: Kabel): assembly of one or more conductors (and/or optical fibres), with a protective covering and possibly filling, insulating and protective material;

- Cord (IEV 461-06-15 / Fr: cordon / De: schnur): flexible cable with a limited number of conductors of small cross-sectional area;

- Core (or insulated conductor) (IEV 461-04-04 / Fr: conducteur (isolé) / De: ader): assembly comprising a conductor with its own insulation (and screens if any);

- Conductor (of a cable) (IEV 461-01-01 / Fr: conducteur (d'un câble) / De: Leiter (eines kabel): conductive part intended to carry a specified electric current;

- Wire (IEV 151-12-28 / Fr: File / De: draht): flexible cylindrical conductor, with or without an insulating covering, the length of which is large with respect to its cross-sectional dimensions
  Note – The cross-section of a wire may have any shape, but the term "wire" is not generally used for ribbons or tapes;

- Socket-outlet (IEV 442-03-02 / Fr: socle de prise de courant/ De: Steckdose): an accessory having socket-contacts designed to engage with the pins of a plug and having terminals for the connection of cables or cords;

- Circuit-breaker (IEV 441-14-20 / Fr: disjoncteur / De: Leistungsschalter): a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit;

- Flexible conductor (IEC Electropedia Area: 461): stranded conductor having wires of diameters small enough and so assembled that the conductor is suitable for use in a flexible cable;

- Insulated cable (IEC Electropedia Area: 461): assembly consisting of:
  - one or more cores,
  - their covering(s) (if any),
  - assembly protection (if any),

- protective covering(s) (if any).

Note – Additional uninsulated conductor(s) may be included in the cable;

- Insulation of a cable (IEC Electropedia Area: 461): assembly of insulating materials incorporated in a cable with the specific function of withstanding voltage;

- Screen of a cable (IEC Electropedia Area: 461): conducting layer or assembly of conducting layers having the function of control of the electric field within the insulation.
  Note – It may also provide smooth surfaces at the boundaries of the insulation and assist in the elimination of spaces at these boundaries;

- Shaped conductor (IEC Electropedia Area: 461): conductor the cross-section of which is other than circular;

- Armour (IEC Electropedia Area: 461): covering consisting of a metal tape(s) or wires, generally used to protect the cable from external mechanical effects;

- Sheath/jacket (North America) (IEC Electropedia Area: 461): uniform and continuous tubular covering of metallic or non-metallic material, generally extruded
  Note – The term sheath is only used for metallic coverings in North America, whereas the term jacket is used for non-metallic coverings;

- Shielding conductor (IEC Electropedia Area: 461): separate conductor or single-core cable laid parallel to a cable or cable circuit and itself forming part of a closed circuit in which induced currents may flow whose magnetic field will oppose the field caused by the current in the cable(s);

- Shield of a cable (IEC Electropedia Area: 461): surrounding earthed metallic layer which serves to confine the electric field within the cable and/or to protect the cable from external electrical influence
  Note 1 – Metallic sheaths, foils, braids, armours and earthed concentric conductors may also serve as shields.
  Note 2 – In French, the term "blindage" may be used when the main purpose of the screen is the protection from external electrical influence;

- Single-conductor cable or single-core cable (IEC Electropedia Area: 461): cable having only one core;
  Note – The French term «câble unipolaire» is more specifically used to designate the cable constituting one of the phases of a multiphase system;

- Solid conductor (IEC Electropedia Area: 461): conductor consisting of a single wire;
  Note – The solid conductor may be circular or shaped;

- Stranded conductor (IEC Electropedia Area: 461): conductor consisting of a number of individual wires or strands all or some of which generally have a helical form.
  Note 1 – The cross section of a stranded conductor may be circular or otherwise shaped.
  Note 2 – The term “strand” is also used to designate a single wire;

- Wire strand (IEC Electropedia Area: 461): one of the individual wires used in the manufacture of a stranded conductor.

1.1.2 Context of power cables within buildings and their electrical installation

Power cables are used to transport electrical power either inside buildings or in electrical distribution grids outdoor.

This study will focus on electrical installations within buildings and behind the electrical meter. This is in line with the working plan 2012-2014[1] and the Consultation Forum (CF-2012-02-EC) regarding power cables. In the working plan and at the Consultation Forum (CF-2012-02-EC) it was explained that this product group concerns cables within domestic and industrial buildings. A rationale for this is that electrical distribution and transmission networks are another market segment with other functional product requirements and players. Cables in distribution are a product group very close to power transformers who are already advanced within the ErP directive[2] process.

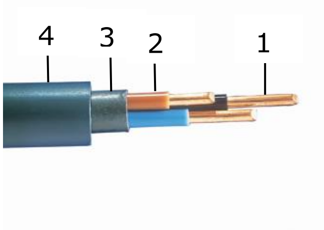
Power cables within buildings can be clearly separated from distribution power cables by product related standards, primarily by its voltage, but also by earthing and electrical armour requirements. Voltage levels used in electrical power cables are:

- High Voltage (HV): voltage whose nominal r.m.s. value lies above 35kV
- Medium Voltage (MV): voltage whose nominal r.m.s. value lies above 1kV and below 35 kV (EN 50160)
- Low Voltage (LV): voltage with a maximum of 1000Vac (IEV 601-01-26 / EN50160).

Low voltage (LV) being the scope of the end application within electrical power installations within buildings and therefore defining the proposed scope of this study.

<u>Different parts of a LV power cable</u>

Basically a cable consists of one or more conductors (a "core" is an insulated conductor), insulation material of the conductors, an inner sheath and an over sheath (Figure 1-1).



1. Solid Copper conductor
2. Insulation of the conductor
3. Inner sheath
4. Over sheath

Figure 1-1: A typical LV cable

Depending on the application (installation method, voltage level, environmental conditions…) an additional mechanical protective cover (armour) and/or an electrical shield can be present (Figure 1-2).

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[1] http://ec.europa.eu/enterprise/policies/sustainable-business/documents/eco-design/working-plan/

[2] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm

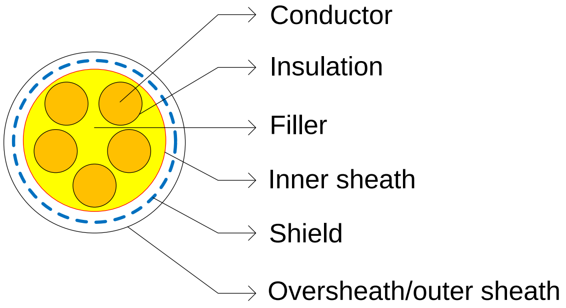


Figure 1-2: Different parts of a LV cable

The different parts of a typical LV cable are:

- Conductor: conductive part intended to carry a specified electric current (IEV 461-01-01). The basic material of the conductor is copper or aluminium. The conductor can be solid or flexible, depending on the application. Copper has a higher electrical conductivity than aluminium, aluminium has a lower weight density (see Table 1). Copper is the most used conductive material in wirings in buildings whereas aluminium is e.g. most used for overhead lines. A LV cables may contain one or more conductors (cores): earthing conductor, phase conductors, neutral conductor). The earthing conductor is sometimes not present in the electrical distribution, for example when TT earthing systems are used.

Table 1-1: Properties of Copper and Aluminium

Property	Copper (Cu-ETP)	Aluminium (1350)
Electrical conductivity at 20°C [MS/m] / [% IACS[3]]	58 / 100	35 / 61
Thermal conductivity at 20°C [W/mK]	397	230
Density [g/cm³]	8.89	2.7

- Insulation : assembly of insulating materials incorporated in a cable with the specific function of withstanding voltage (IEV 461-02-01). Insulation material can consist of thermoplastic compounds such as PVC (Poly Vinyl Chloride), PE (Polyethylene); thermosetting compounds such as XLPE (Cross-linked Polyethylene), EPR (Ethylene Propylene Rubber) or other synthetic or natural materials.

[3] IACS: International Annealed Copper Standard

- Filler: This material is used in multi conductor cables to occupy interstices between insulated conductors. The filler material shall be suitable for the operating temperature of the cable and compatible with the insulating material.

- Sheath: Uniform and continuous tubular covering of metallic or non-metallic material, generally extruded (IEV 461-05-03). PVC (Poly Vynil Chloride), PE (Polyethylene); thermosetting compounds such as XLPE (Cross-linked Polyethylene), EPR (Ethylene Propylene Rubber) or commonly used.

- Armour (*Protective cover)*: covering consisting of a metal tape(s) or wires, generally used to protect the cable from external mechanical effects (IEV 461-05-06*)* (see Figure 1-2). This is not often used in electrical power cables within buildings, it is mainly used in outdoor cables and in Low Voltage IT earthing systems e.g. Norway[4].

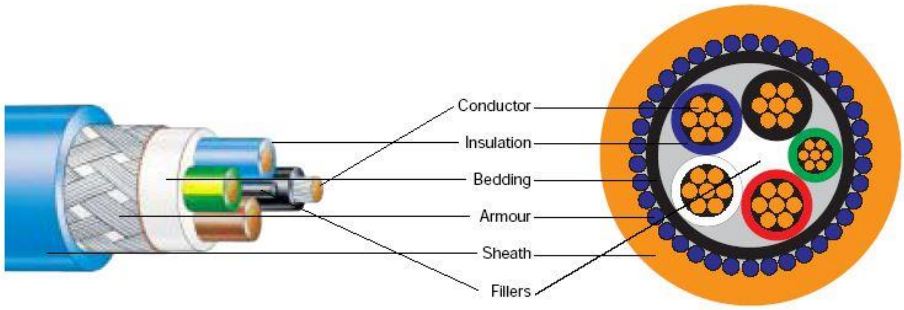
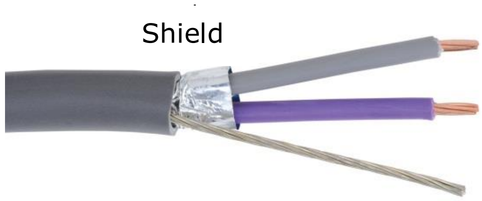


Figure 1-2*: An armoured cable*

Shield (of a cable) (Figure 1-3): surrounding earthed metallic layer which serves to confine the electric field within the cable and/or to protect the cable from external electrical influence (IEV-461-03-04). This is a commonly used cable in industry (e.g. in areas with Electro Magnetic Interferences). Sometimes this cable is also used in residential buildings e.g. Sweden (Europacable)



[4] See comments Europacable – first stakeholder meeting

Figure 1-3: A shielded LV cable

Copper is the most used conductive material in wirings in buildings. Besides the electrical losses, the use of copper, the insulation material and the method of installation are the most significant environmental aspects related to power cables.

Electrical losses in power cables

Cable electrical losses are determined by Ohm's law of physics and are also called Joule losses. The magnitude of these losses increases with the square of the load current and is proportional to the cable electrical resistance. As a consequence without loading there are no cable losses, hence the entire electrical installation system (e.g. way of installation, load of the cable, duration of use, interfaces with a variety of electrical equipment) needs to be considered. For instance there is a relation between the total cable losses in an electrical installation and the topology of the electrical installation.
When designing circuits for lighting three different topologies are commonly used:

- Bus approach (e.g. DALI), where the switching is done near the lighting point by means of a local relay
- Relays (interrupters) located in the distribution board resulting in a star topology
- Traditional wiring, by means of a mechanical switch connected to the lighting point

The amount of cable used in an electrical installation depends among others on the kind of topology that is applied. A star topology, connecting each individual appliance to a central point by a dedicated cable, will increase the total length of cable used in the installation. The average load per cable decreases compared to a traditional or bus topology, therefore cables with a smaller CSA could be used. In practice however, the same cable sections are used as in other topologies, unless the electrical installation design is calculated.

Electrical installations in buildings

Electrical installations in buildings are defined by the international standard IEC 60364 series and fixed wiring products (cables) in the standards IEC 60227 and IEC 60245. Electrical installation rules at EU member state level are in general according to these international and European standards, however there may exist deviations and/or additional requirements at member state level. The above mentioned standards are primarily concerned with safety aspects of the electrical installation. However cables with cross section areas beyond what is required for safe installations could lead to a more economic operation and energy savings.

Cables are part of electrical circuits in electrical installations. The current-carrying capacity is limited by circuit breakers because of safety reasons. Electrical circuits can have socket-outlets or can be directly connected to loads, e.g. for lighting. The power electrical installation system is typically described with a so-called 'One-line diagram'[5]. Examples of one-line diagrams of electrical circuits with typical IEC component symbols are included in Figure 1-4 and Figure 1-5. The latter is a two-level electrical circuit, meaning that there is a main distribution board with circuit breakers and a second-level distribution board(box) with circuit breakers directly connected to the loads.

[5] http://en.wikipedia.org/wiki/One-line_diagram

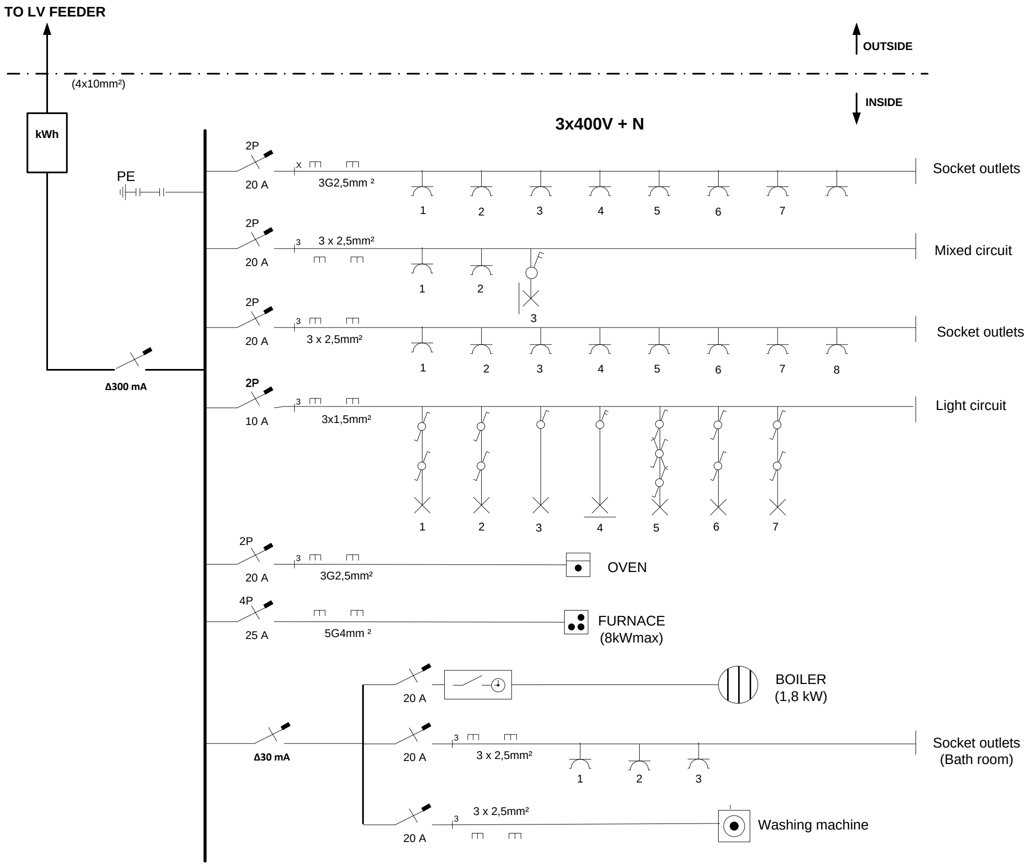


Figure 1-4: Simplified residential electrical diagram

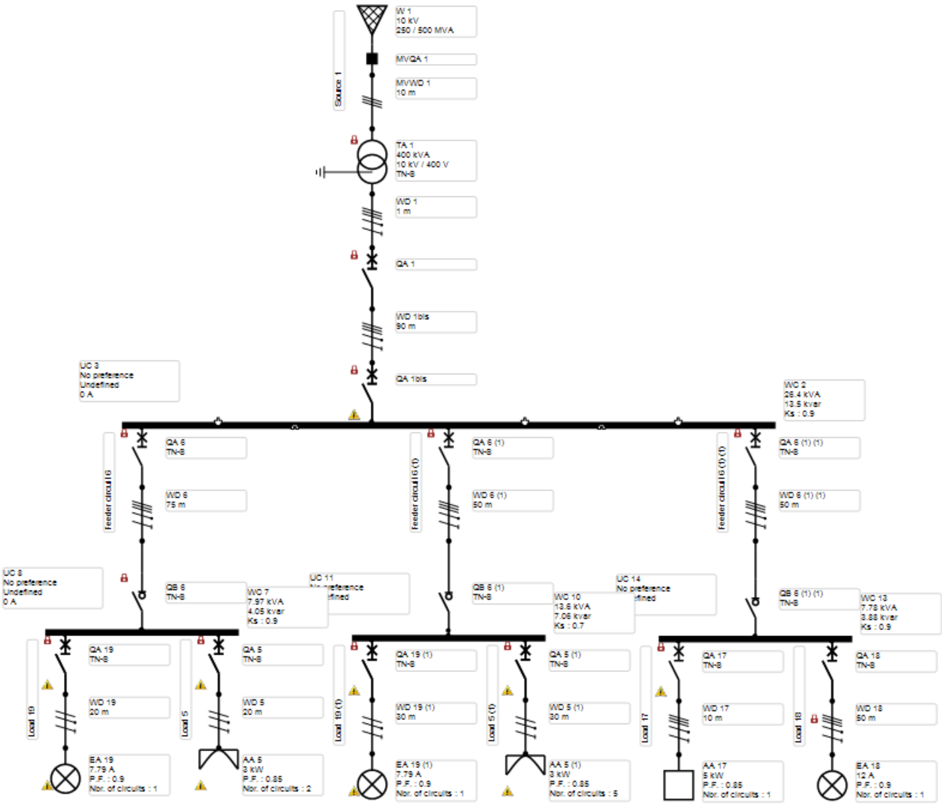


Figure 1-5: Simplified electrical diagram with 2 circuit levels

1.1.3 First proposed scope of this study

Given the context (see 1.1.2) the scope proposal is in summary: **'losses in installed power cables in electric circuits in buildings after the meter' taking into account the electrical installation as a system**, the power cable being the product put into service by the electrical installer in a circuit of an electrical installation in a building.
The electrical installation including loads are taken into account at system level, this is explained in more detail in chapter 3 amongst others it means that the installation will be analysed at the level needed related to cable losses.

More in detail, the **scope** of this study "losses in installed power cables in buildings" covers Low Voltage power cables for fixed wiring used in indoor electrical installations in:

- Residential buildings;
- Non-residential buildings:

The non-residential buildings can be further categorised as follow (Ecofys[6]):

- Public/commercial buildings:
    - Trade facilities: Trade, retail, wholesale, mall
    - Gastronomic facilities: Hotels, restaurants, pubs, café's…
    - Health facilities: Hospitals, surgeries,..

[6] Ecofys report, Panorama of the European non-residential construction sector, 9 December 2011

- Educational facilities: Schools, colleges, academies, universities, nurseries,..
  - Offices
  - Other buildings: Warehouses, recreation facilities…
- Industrial buildings: factories, workshops, distribution centres….

Remarks:

- Industrial buildings can consist of production halls and attached or detached offices. Both are in the scope of this study;
- Process installations which are in general outdoor installations are out of the scope.

Practically, the scope includes low voltage cables on the customer side of the electricity meter (utility cables are out of the scope) inside the above mentioned buildings. These cables can be single core or multicore, shielded…. depending on the application and on the European and National wiring regulations.

Explanation of the terms used in the scope:

- "Low voltage": voltage with a maximum of 1000Vac (IEV 601-01-26). In Europe the standard nominal voltage for public Low Voltage is Un=230Vac r.m.s with a maximum variation of $\pm$ 10% (see EN 50160). For four wire LV distributions systems the voltage between phase and neutral is 230Vac r.m.s and 400Vac r.m.s between 2 phases.

- "Fixed wiring": refer to the method of installation of the cable in the building e.g. enclosed in conduit, installed on a cable tray, cable trunking, cable ladder…. (see IEC 60364-5-52, Table A.52.3)

- "Insulated cables": assembly consisting of:
  - one or more cores,
  - their individual covering(s) (if any),
  - assembly protection (if any),
  - protective covering(s) (if any).

  Note – Additional un-insulated conductor(s) may be included in the cable

- "Single core cables": cable having only one core
  - Note – The French term «câble unipolaire» is more specifically used to designate the cable constituting one of the phases of a multiphase system.

Remark: Further in this study the word "power cables" will be used as a general term for single core or multi-core power cables, unless otherwise stated.

Out of the scope:

- Losses in circuit breakers;
- Losses or inefficiency in the loads connected to the circuit;
- Losses due to poor connections ("A recent study found that average electrical distribution system losses accounted for 2% of a plant's annual energy use. Losses due to poor connections represented one-third of these losses and accounted for 40% of the savings after corrective actions were taken. (Source: U.S. Department of Energy")[7];
- Utility cables for transmission (HV) and distribution (MV,LV) of electrical energy;

[7] ECI Publication No Cu0192: APPLICATION NOTE INFRARED SCANNING FOR ENERGY EFFICIENCY ASSESSMENT -Paul De Potter - January 2014

- Power cables for Nuclear power plants (require higher-quality cables that meet stringent Nuclear Regulatory Commission standards);
- Power cables for hazardous locations (in ATEX zones);
- Cables used for power plants such as PV, Wind, ….;
- Outdoor cables: Cables used in process installations (e.g. chemical and petrochemical plants), railway cables,..;
- Cables for mobile applications: (electric) cars, ships, metro, …
- Busbar Trunking systems;

Outside of the scope of Tasks 1-6, but in the scope of Task 7 for a review on potential negative impact related to proposed policy measures (if applicable):

- Some of the installation cables included in the scope of this study are also used in other sectors like machinery construction for wiring inside machines. Measures on product level could as such have an impact on machine construction.
- Socket-outlets, junction boxes, cable installation systems (ducting systems, trunking systems..), cable accessories,…,
- Building design and construction
- LV distribution board

Outside of the scope of Tasks 1-6, but in the scope of Task 7 for review on potential loopholes related to proposed policy measures (if applicable):

- utility cables, be it low Voltage, Medium Voltage and High Voltage utility cables,
- all the cables with a rated voltage above 1000Vac r.m.s,
- extra Low voltage (e.g. 24Vdc/ac; 12Vac…) cables,
- connection of the electrical distribution board of the building to the LV distribution grid (via a buried or overhead cable),
- the electrical distribution boards, internal wiring in the distribution boards, (smart) KWh-meter, RCD… ,
- data cables (Ethernet cable, TV ..), telephone cables, lift cables, safety cables (fire alarm..), , welding cables, instrumentation cable,… In general these are special purpose power cables which are not fixed wired (flexible lift cables) or have very low load currents (cables to fire detectors, data cables..).
- DC cables for PV installations
- power cords of the electrical apparatus and the internal wiring of these apparatus,
- building automation systems, lighting controls, …..

1.1.4 Prodcom category or categories

The only category found in Prodcom, related to the scope of this study, is the category with NACE code 27321380.

Table 1-2 ProdCom data

Prodcom NACE code	Description
27321380	Other electric conductors, for a voltage <= 1000 V, not fitted with connectors

1.1.5 Categories according to IEC, EN- or ISO-standard(s)

Cables can be roughly divided into High voltage cables ($\geq$ 1kVac) & Low voltage cables (<1kVac). These are the topics of respectively Working Group 16 and Working Group 17 of IEC TC 20 (Electric Cables).

The following sections list IEC standards defining subcategories of cables according to the field of application.

1.1.5.1 IEC 60228

IEC 60228: "Conductors of insulated cables" defines 4 classes for conductors:
- Class 1: solid conductor
- Class 2: stranded conductors
- Class 5: flexible conductors
- Class 6: flexible conductors which are more flexible than class 5

Whereas Class 1 and 2 conductors are intended for use in cables for fixed installation. Class 5 and 6 are intended for use in flexible cables and cords but may also be used for fixed installation.
Functional difference is the minimum bending radius which is expressed in x times the outer diameter of the cable.

1.1.5.2 IEC 60227-1

The following classes and types are defined in **IEC 60227-1**: "Polyvinyl chloride cables of rated voltage up to and including 450/750V – general requirements":

0. Non-sheathed cables for fixed wiring.
- **01.** Single-core non-sheathed cable with rigid conductor for general purposes (60227 IEC 01).
- **02.** Single-core non-sheathed cable with flexible conductor for general purposes (60227 IEC 02).
- **05.** Single-core non-sheathed cable with solid conductor for internal wiring for a conductor temperature of 70 °C (60227 IEC 05).
- **06.** Single-core non-sheathed cable with flexible conductor for internal wiring for a conductor temperature of 70 °C (60227 IEC 06).
- **07.** Single-core non-sheathed cable with solid conductor for internal wiring for a conductor temperature of 90 °C (60227 IEC 07).
- **08.** Single-core non-sheathed cable with flexible conductor for internal wiring for a conductor temperature of 90 °C (60227 IEC 08).

1. Sheathed cables for fixed wiring.
- **10.** Light polyvinyl chloride sheathed cable (60227 IEC 10).

1.1.5.3 IEC 60245-1

IEC 60245-1: "Rubber insulated cables – Rated voltages up to and including 450/750 V – Part 1: General requirements" defines the following classes and types:

0 Non-sheathed cables for fixed wiring
- **03** Heat-resistant silicone insulated cable for a conductor temperature of maximum

180 °C (60245 IEC 03).

04 Heat-resistant ethylene-vinyl acetate rubber insulated, single-core non-sheathed 750 V cable with rigid conductor for a maximum conductor temperature of 110 °C (60245 IEC 04).

05 Heat-resistant ethylene-vinyl acetate rubber insulated, single-core non-sheathed 750 V cable with flexible conductor for a maximum conductor temperature of 110 °C (60245 IEC 05).

06 Heat-resistant ethylene-vinyl acetate rubber or other equivalent synthetic elastomer insulated, single-core non-sheathed 500 V cable with rigid conductor for a maximum conductor temperature of 110 °C (60245 IEC 06).

07 Heat-resistant ethylene-vinyl acetate rubber or other equivalent synthetic elastomer insulated, single-core non-sheathed 500 V cable with flexible conductor for a maximum conductor temperature of 110 °C (60245 IEC 07).

1.1.6 Other product-specific categories

In general cables can be categorised according to their field of application or the composition of the cable.

Categories according to the **field of application** (typically found in cable catalogue):

- Energy (or power) cables: Cables for transmission & distribution of electrical energy
  - LV, MV and HV (AC/DC) cables
  - Underground / overhead cables
- Industrial cables
  - LV,MV,(HV) cables
  - Power, control, instrumentation.. cable
- Building wire cable
  - Cables for fixed wiring (e.g. Class 1&2– EN60228)
  - Other (flexible) cables (e.g. Class 5&6 – EN 60228)
- Special purpose cables (automotive, railway, renewables, military…)
- Communication cables (data, telephone..)

Categories according to the **composition of the cable**:

- Conductor material: Copper or Aluminium
- Insulation and sheath material: bare or insulated conductors/cables. Insulation and sheath material depends on:
  - The rated voltage level: LV, MV, HV
  - Mechanical requirements: bending radius, elongation, tensile strength, abrasion, max diameter, ..
  - Chemical requirements: resistance to chemical products (oil, fuels, acids,..) and resistance to fire/heat, halogen free

A further categorisation can be made, based on:

- Nominal Cross sectional area of the conductors (expressed in mm²): value that identifies a particular size of a conductor but is not subject to direct measurement (IEC 60228)
- The construction of the conductor: Solid, stranded, flexible
- The amount of conductors in the cable: single core or multicore

1.1.7 Proposal for primary product performance parameter or 'functional unit'

Knowing the functional product used in this study we now further explain what is called the "functional unit" for power cables.

In standard 14040 on life cycle assessment (LCA) the functional unit is defined as "the quantified performance of a product system for use as a reference unit in life cycle assessment study". The primary purpose of the functional unit is to provide a calculation reference to which environmental impacts (such as energy use), costs, etc. can be related and to allow for comparison between functionally equal electrical power distribution cables and/or circuits. Further product segmentations will be introduced in this study in order to allow appropriate equal comparison.

The primary functional performance parameter in this study is **"current-carrying capacity".**

The "current-carrying capacity" of a cable or (insulated) conductor is defined as the maximum value of electric current which can be carried continuously by a conductor (a cable), under specified conditions without its steady-state temperature exceeding a specified value (see IEV 826-11-13). The current-carrying capacity is expressed in Amperes [A].

The current-carrying capacity of a cable depends on:

- Conductor material: Cu or Al or alloys;
- Nominal cross sectional area of the conductor (expressed in mm²);
- Insulation material: maximum operating temperature (e.g. PVC=70°C, XLPE= 90°C);
- Ambient temperature at the place where the cable is installed;
- Method of installation: The installation method has an impact on the heat transfer from the conductor to the environment.

Note: in some North-American countries the word "**ampacity**" is used to express the current-carrying capacity.

1.1.8 Secondary product performance parameters

These parameters can be divided in two subcategories:

- secondary product performance parameter related to the construction of the cable;
- secondary product performance parameter related to the use of the cable.

1.1.8.1 Secondary product performance parameters related to the construction of the cable

The secondary product performance parameters related to the construction of the cable are:

- **Nominal Cross-Sectional Area (CSA):** a value that identifies a particular size of conductor but is not subject to direct measurement, expressed in mm² (IEC 60228). The csa of the conductor is standardized: e.g. 0.5 mm², 0.75mm², 1 mm², 1.5 mm², 2.5 mm² ….

  The cross-sectional area of conductors shall be determined for both normal operating conditions and for fault conditions according to (IEC 60364-1):

- their admissible maximum temperature;
- the admissible voltage drop;
- the electromechanical stress likely to occur due to earth fault and short circuit currents;
- other mechanical stress to which the conductor can be subjected;
- the maximum impedance with respect to the functioning of the protection against fault currents;
- the method of installation.

Note: The items listed above concern primarily the safety of electrical installations. Cross-sectional areas greater than those for safety may be desirable for economic operation.

- **DC resistance (R_{20}):** Direct current resistance of the conductor(s) at 20°C expressed in Ohm/km (IEC 60228 – Annex A). The DC resistance of solid conductors (Class 1) are lower than these of flexible conductors (Class 5,6), e.g. For a Class 1, 1 mm² Cu wire R_{20}= 18.1 Ohm/km; for a class 5, 1 mm² Cu wire R_{20}= 19.5 Ohm/km;

- **Rated voltage Uo/U**: The rated voltage of a cable is the reference voltage for which the cable is designed and which serves to define electrical tests (IEC 60227-1). The rated voltage is expressed by the combination of two values Uo/U expressed in volts:
  - U0 is the r.m.s value between any insulated conductor and “earth” whereas
  - U is the r.m.s value between any two-phase conductor of a multicore cable or of a system of single-core cables.

- **Insulation material:** synthetic insulation materials can be roughly divided into:
  - Thermoplastics (PVC, PE, PP,..);
  - Thermosettings (Neoprene, Silicone Rubber…);
  - Elastomers (XLPE, EPR,…).

  The selection criteria of the insulation material depends on the electrical (rated voltage, ..) and physical (temperature range, flexibility, flammability, chemical resistance…) requirements of the application.

- **Conductor material (Cu, Al):** Copper and aluminium are the most commonly used metals as conductors. The compositions of copper and aluminium wire for the manufacturing of electrical conductors are specified in respectively EN13601/13602 and EN1715.

- **Number of cores in the cable:** In general a distinction is made between single core and multi-core cables. A single core cable consists of only one conductor covered by an insulation material (1 or 2 layers). A multi-core cable consists of 2, 3, 4, 5 or more cores, each individually insulated and globally covered by a sheath. In general conductors in a cable have the same CSA, but there are also cables with other combinations. For instance for balanced three-phase systems the neutral can have a smaller CSA than the phase conductors, sometimes indicated as 3.5 (3 conductors with the same size, 1 conductor with a smaller CSA) or 4.5 (4 conductors with the same size, 1 conductor with a smaller CSA). Also the protective earth conductor can have a smaller CSA.

- **The construction of the conductor**: Solid, stranded, flexible. Solid wire, also called solid-core or single-strand wire, consists of one piece of metal wire. Stranded wire is composed of smaller gauge wire bundled or wrapped together to form a larger conductor. The type of construction mainly has an effect on the flexibility/bending radius, but it has also an effect on the AC resistance of the cable.

1.1.8.2 Secondary product performance parameter related to the use of the cable

Secondary product performance parameters related to the use of the cable in an electrical installation system are the following:

At the level of **the electrical installation system**:

- Supply parameters & topology of the grid:
    - Nominal voltage (U and/or Uo)
    - Maximum and minimum fault currents to earth and between live conductors
    - Maximum supply loop impedance to earth (Z41), given as a minimum fault current
    - AC Grid system (TT, TN, IT) / DC (marginal, see BAT)
    - Single phase or three phase electrical installation. A single phase installation consists of single phase circuits. A three phase installation can consist of any combination of single phase and three phase circuits;

- Design of the electrical distribution system in the building (see FprHD 60364-8-1)
    - Main and/or sub distribution board (levels). Small installations have just one level, the main distribution board feeding the circuits. Larger installations in general have two levels, the main distribution board serving secondary distribution boards. Exceptionally, very large installations or installations with special design requirements may have a third level.
    - Installation cable length: the total length of all fixed wired power cables used in the total electrical installation of a building;
    - Method of installation: in cable trunk, inside the wall, in open air, grouped, indoor/outdoor. Reference installation methods and their corresponding correction factors are defined in IEC 60364-5-52;

- External influences (see IEC 60364-5-51), such as:
    - Environmental conditions:
        - Ambient temperature: A correction factor for ambient temperatures other than 30°C has to be applied to the current-carrying capacities for cables in the air (IEC 60364-5-52). Higher ambient temperatures have a negative effect on the current-carrying capacity of the cable, e.g. a correction factor of 0.87 has to applied for PVC cables installed in locations with a ambient temperature of 40°C;
        - Presence of corrosive or polluting substances: the sheath material of the cable must be resistant to the substances at which it is exposed to;
    - Utilisation of the building: The utilisation of the building has a significant impact on the choice of the cables, especially on the fire behaviour of the cables. Important building aspects related to this topic are:
        - Condition of evacuation in case of emergency
        - Nature of processed or stored material

- Construction of the building: cables must be conform to the performance criteria of the Construction Product Directive / Construction Product Regulation (see further on)

At the level of **the circuit**:

- Voltage drop over the cable in a circuit (Volt): an electric current flowing through a resistive material (conductor) creates a voltage drop over the material. The voltage drop depends on the resistance of the conductor (Cu, Al), the amount of current flowing through the conductor (depends on the electrical load) and the length of the cable. The voltage drop can be calculated with the following formula (IEC 60364-5-52):

$$u = b\left(\rho 1\frac{L}{S}cos\varphi + \lambda L\ sin\varphi\right)Ib$$

Where

u= voltage drop in volts;

b= the coefficient equal to 1 for three-phase circuits and equal to 2 for single-phase circuits;

ρ1= the resistivity of the conductor in normal service, taken equal to the resistivity at the temperature in normal service, i.e. 1.25 times the resistivity at 20°C, or 0.0225 $\Omega mm^2/m$ for copper and 0.036 $\Omega mm^2/m$ for aluminium;

L= the straight length of the wiring systems in metres;

S= the cross-sectional area of conductors, in mm2;

cos φ= the power factor; in the absence of precise details, cos φ is taken as equal to 0,8 ;

λ= the reactance per unit length of conductors, which is taken to be 0,08 mΩ/m in the absence of other details;

Ib is the design current (in amps);

- Load current (Ampere): This is the design current of the electric circuit and is determined by the electric load in normal operation connected to the circuit. The load current can be calculated as follow:

$Ib = P/(Uo.cos\ \varphi)$ for single phase systems
$Ib = P/(\sqrt{3}.U.cos\ \varphi)$ for three phase systems

Where P= active power of the load (Watt)
Uo= nominal voltage between line and neutral
U= nominal voltage between the lines
Cos φ = power factor of the load

- In: is rated current for the circuit and is determined by the protective device (safety fuses or circuit breakers) of the circuit;

- Single phase or three phase circuit;

- Circuit topology: radial, loop, line, tree circuit;

- Load factor (LF) (IEV 691-10-02):
  The ratio, expressed as a numerical value or as a percentage, of the consumption within a specified period (year, month, day, etc.), to the consumption that would result from continuous use of the maximum or other specified demand occurring within the same period

  Note 1 – This term should not be used without specifying the demand and the period to which it relates.
  Note 2 – The load factor for a given demand is also equal to the ratio of the utilization time to the time in hours within the same period.
  As a consequence the load factor is an important parameter for calculating the energy losses in the cable;

- Load form factor (Kf) (derived from IEV 103-06-14): the ratio of the root mean squared (r.m.s) Power to the average Power (=Prms/Pavg);

  - The r.m.s or root mean square value is the value of the equivalent direct (non-varying) voltage, current, power which would provide the same energy to a circuit as the sine wave. That is, if an AC sine wave has a r.m.s value of 240 volts, it will provide the same energy to a circuit as a DC supply of 240 volts. The r.m.s value can be calculated as follow:

$$Prms = \sqrt{\frac{1}{t2 - t1} \int_{t1}^{t2} (V(t) \times I(t))^2 dt}$$

For a sine wave (eg. Grid voltage, power): y= $a\sin(2\pi f t)$ with amplitude “a” and frequency “f”, the r.m.s value is $rms = a/\sqrt{2}$. or $a \times 0.707$

  - The avg or average value is normally taken to mean the average value of only half a cycle of the wave. If the average of the full cycle was taken it would of course be zero, as in a sine wave symmetrical about zero, there are equal excursions above and below the zero line.
  -

$$P_{\text{avg}} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} V(t) I(t) \, \mathrm{d}t$$

For a sine wave (eg. Grid voltage, power): y=a sin(2πft) with amplitude “a” and frequency “f” , the avg value is $avg = a \times \frac{2}{\pi} = a \times 0.637$

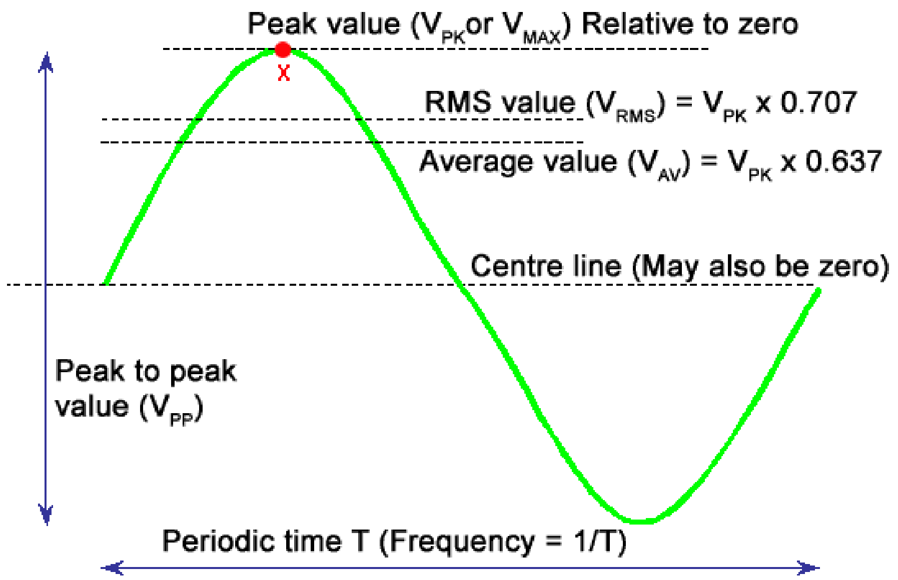


Figure 1-6: Peak-, r.m.s-, avg value of a sine wave

- The equivalent operating time at maximum loss, in h/year; (IEC 60287-3-2) : is the number of hours per year that the maximum current Imax would need to flow in order to produce the same total yearly energy losses as the actual, variable, load current;

$$T = \int_{0}^{8760} \frac{Ib(t)^2 . dt}{Imax^2}$$

where

- t is the time, in hours;
- Ib(t) the design current in function of time, in A;
- Imax is the maximum load on the cable during the first year, in A;

The energy losses according IEC 60287-3-2 are:

$$energy\ loss\ during\ the\ first\ year\ = \quad I^2 max.\ RL\ .L.NP.NC\ .T$$

where

- Imax is the maximum load on the cable during the first year, in A;
- RL is cable resistance per unit length;
- L is the cable length, in m;
- NP is the number of phase conductors per circuit (=*segment in this context*);
- NC is the number of circuits carrying the same type and value of load;
- T is the equivalent operating time, in h/year.

Be aware that the formula used in IEC 60287-3-2 is only used to calculate the cable losses for cable segments. Compared to circuits the load is situated at the end of the cable, having an equal load (current) over the total length of the cable.

- Power factor (IEC 60364-5-52) of the load: is defined as the ratio of active power (P – kWatt) to the apparent power (S′ – kVA). The power factor is equal to cos φ for linear loads (i.e. loads with sinusoidal currents).

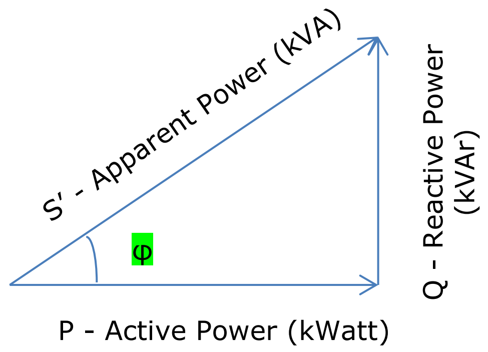


Figure 1-7: Relationship between active-, reactive- and apparent power

Where:

Active Power (P) (IEV 141-03-11): For a three-phase line under symmetric and sinusoidal conditions, the active power is $P = \sqrt{3}\, UI \cos\varphi$, where U is the r.m.s value of any line-to-line voltage, I is the r.m.s value of any line current and φ is the displacement angle between any line-to-neutral voltage and the corresponding line current.

Apparent Power (S′) (IEV 131-11-41): product of the r.m.s voltage U between the terminals of a two-terminal element or two-terminal circuit and the r.m.s electric current I in the element or circuit $S' = UI$ expressed in VoltAmpere, VA. For a three-phase system, the apparent power is $S' = \sqrt{3}\, UI$.

- Short-circuit intensity: Short-circuits causes large currents in the conductors which lead to thermal stresses in these conductors. Therefore the breaking time for a short-circuit may not be greater than the time taken for the temperature of the conductors to reach maximum permissible value. The maximum thermal stresses of a cable depends on:
    - Insulation material (PVC, XLPE,..)
    - Conductor material (Cu, Al)
    - Cross sectional area of the conductors

- Harmonic currents (will be defined later in task 3).

- Kd distribution factor (defined for this study): distribution of the load over the cable of a circuit. A circuit can have several connection terminals along the circuit with different loads attached to it. As a result the current passing along the circuit reduces towards the end. This distribution factor compensates this effect by reducing the cable length to an equivalent cable length at peak load. Note this is probably only relevant for small loads, as in general larger loads are fed by dedicated circuits serving one single load;

- Rated Diversity Factor (IEC 61439): the rated current of the circuits will be equal to or higher than the design current (or assumed loading current). The Rated Diversity Factor recognizes that multiple loads are in practice not fully loaded simultaneously or are intermittently loaded.

- Amount of junction boxes per circuit;

- Number of nodes per circuit;

- Circuit levels 1 and 2 (defined for this study) (see also Figure 1-5);

    - Circuit level 1 cables are cables that feed the secondary distribution boards from the main distribution board;
    - Circuit level 2 cables are cables that are connected to the end loads.

- Number of load per circuit;

- Skin effect, skin depth[8]: skin effect is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor. It decreases with greater depths in the conductor. The electric current flows mainly at the "skin" of the conductor, between the outer surface and a level called the skin depth δ. The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor.

- Lifetime of the cable: the lifetime of a cable depends mainly on the nominal load current and the environmental conditions (temperature, presence of corrosive or polluting substances ...) in which the cable is installed. Short circuits have an negative impact on the lifetime, because of the high conductor temperatures caused by the short circuit currents.

1.1.9 First screening

Objective:
The first product screening is a preliminary analysis that sets out the recommended scope for the subsequent Tasks. As the full study investigates the feasibility and appropriateness of Ecodesign and/or Energy Labelling measures, the first product screening entails an initial assessment of the eligibility and appropriateness of the product group envisaged.

Important note: These are indicative for a first screening only and will be updated in later chapters.

1.1.9.1 Envisaged product application categories

When the classification is performed according the main application of the circuit, 12 categories are defined (see Table 1-3).

[8] http://en.wikipedia.org/wiki/Skin_effect

Table 1-3: Application categories

	Sector	Residential			Services			Industry		
Circuit level 1	Application category id	1			2			3		
Circuit level 2	type of application	Lighting circuit	Socket-outlet circuit	Dedicated circuit	Lighting circuit	Socket-outlet circuit	Dedicated circuit	Lighting circuit	Socket-outlet circuit	Dedicated circuit
	Application category id	4	5	6	7	8	9	10	11	12

At circuit level 1 there is one type of circuit per sector, e. g. Figure 1-5. The main function of a level 1 circuit is to feed the secondary distribution boards. Standalone single family houses in the residential sector generally have one circuit level, but for instance apartment buildings have two circuit levels (secondary distribution board per dwelling).

At circuit level 2 we differentiate between lighting circuits, socket-outlet circuits and dedicated circuits (see for example in Figure 1-4 and Figure 1-5). Each circuit type has one or more typical topologies. For instance lighting circuits can be designed as single line circuit (no branches), as a tree by means of junction boxes (with one branch per node), or as a star. Socket-outlet circuits in general are single line circuits or looped circuits. Dedicated circuits serve mostly just one load. For instance a motor or pump with a dedicated circuit breaker in the distribution board and a cable between circuit breaker and load. The load is thus located at the end of the dedicated circuit. For lighting and socket-outlet circuits the load is distributed along the circuit.

Acronyms for circuit identification based upon the above mentioned application categories in Table 1-3:
RESidential Level1 circuit: RESL1
SERvices Level1 circuit: SERL1
INDustry Level1 circuit: INDL1
RESidential Level2 Lighting circuit: RESL2L
SERvices Level2 Lighting circuit: SERL2L
INDustry Level2 Lighting circuit: INDL2L
RESidential Level2 Socket-outlet circuit: RESL2S
SERvices Level2 Socket-outlet circuit: SERL2S
INDustry Level2 Socket-outlet circuit: INDL2S
RESidential Level2 Dedicated circuit: RESL2D
SERvices Level2 Dedicated circuit: SERL2D
INDustry Level2 Dedicated circuit: INDL2D

1.1.9.2 Parameters determining power loss in cables

This section elaborates the physical parameters of a power cable related to losses in the cable.

As stated in the previous section the power losses are proportional to the cable resistance (R). The resistance of a cable in circuit at a temperature t can be calculated by the formula: R= ρ_t.l/A (Ohm). This means the losses in a circuit can be diminished by:

- reducing the specific electrical resistance (ρ) of the conductor material;
- increasing the cross sectional area (A) of the cable;
- reducing the total length (l) of cable for a circuit.

In annex 1-B a closer look is taken at these physical parameters and at how manipulation of these parameters can contribute to smaller power losses in power cables.

1.1.9.3 Preliminary analysis according to working plan

The preliminary analysis in this section is based upon data from the "Modified Cable Sizing Strategies, Potential Savings" study[9] – Egemin Consulting for European Copper Institute – May 2011. This study is also referred to in the ErP Directive Working plan 2012-2014[10]. It focuses on the use of electrical conductors with cross-sections beyond the minimum safety prescriptions, which helps to achieve energy savings and cost-effectiveness.

1.1.9.3.1 Market and stock data for the first screening

Electrical installations in buildings were modelled by their content of conductive material. The analysis was carried out considering the equivalent content of copper of the electrical installation (largely dominated by the electrical conductor).

Buildings can be split into three main categories:

- Residential;
- Non-residential;
  - Industry;
  - Services.

This classification (residential, industry, services) corresponds with available statistical and forecast data on electricity consumption, which allows making estimates of potential energy savings.
Annual sales of wiring, expressed as kilotons equivalent copper, are estimated to be some 760 kTon in 2010, and are expected to increase to 924 kTon in 2030 (see Table 1-4).

Table 1-4: Sales of power cables (kTon Copper)[11]

Annual Sales (kTons eq. Copper)	2000	2005	2010	2015	2020	2025	2030
Industry	226	245	241	253	266	279	293
Services	202	219	216	227	238	250	263
Residential	284	308	303	318	334	351	368
Total	712	772	760	798	838	880	924

The total amount of copper installed in buildings ('stock') is estimated to be some 18788 kTon in 2010, expected to increase to 21583 kTon in 2030 (see Table 1-5).

[9] http://www.leonardo-energy.org/white-paper/economic-cable-sizing-and-potential-savings
[10] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/

[11] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/

Table 1-5: Stock of power cables (kTon of Copper)[11]

Stock (kTons eq. Copper)	2000	2005	2010	2015	2020	2025	2030
Industry	5991	6102	6538	6951	7395	7453	7511
Services	4338	4419	4734	5033	5355	5397	5439
Residential	6886	7014	7515	7989	8500	8567	8633
Total	17215	17536	18788	19974	21250	21417	21583

The gap between the stock increase and the cumulative 5 years sales is due to refurbishment, maintenance and extension of existing installations as well as dismantling of old buildings.

Information sources were:

- Residential and non-residential new construction and refurbishment activity (Euroconstruct database)
- Demographic statistics, households statistics and projections (Eurostat, European Union portal, European Environmental Agency)
- Copper wire and cable consumption (European Copper Institute)

Assumptions were:

- 30 kg of equivalent copper per electrical installation of a household.
- Stock in non-residential buildings = 1.5 times the stock in residential buildings (based on copper wire and cable consumption statistics).

1.1.9.3.2 Cable loading data for first screening

Losses in electrical cables are related to the loading (see 1.1.9.2). This electric loss is therefore directly related to the overall electricity consumption in the buildings concerned.
Hence, the Reference scenario for the calculations is defined by the projections made by the European Commission[12] regarding electricity consumption in buildings and industrial indoor sites. Note that probably part of the industry electricity consumption (see Table 1-6) can strictly not be seen as cables inside buildings, they could be located outdoor but due to a lack of data this is neglected at this stage.

Table 1-6: Final affected energy demand, related to power cables[13]

FINAL ENERGY DEMAND - Reference Scenario	Unit	2010	2015	2020	2025	2030
Industry	TWh	1073	1152	1207	1279	1329
Services	TWh	775	832	872	924	960
Residential	TWh	950	1021	1069	1133	1177
Total Electricity	TWh	2798	3005	3148	3336	3466
Total Electricity	PJelec	10074	10818	11334	12011	12478
Total energy	PJ prim	25182	27045	28332	30024	31194

1.1.9.3.3 Estimated losses in cables in buildings

[12] http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

In the Modified Cable Sizing Strategies, Potential Savings" study – Egemin Consulting for European Copper Institute – May 2011, referred to in the ErP Directive Working plan 2012-2014[13], four electrical systems were defined modelling and representing a small office, a large office, a small logistics centre and a large industrial plant.

The calculated averaged energy loss in power cables for the sectors defined in this study was **2.04%.**

Some stakeholders made remarks to the above mentioned study[14]. In the next sections we will re-analyse the assumptions made in the Egemin study.

1.1.9.4 Review of losses

In the following sections the losses in the circuits, classified according the product application categories in 1.1.9.1, have been calculated. Analogue to the study elaborated in 1.1.9.3.3, a residential and non-residential model have been worked out based upon empirical findings. Beware that every individual installation and loading can vary a lot compared to those assumptions.
The parameters used in the models are explained in chapter 3 of this report. The length of the circuits in the models is based upon the answers on the questionnaire for installers[15]. The acronyms used for the circuit identification are listed in 1.1.9.1.

The loss ratio used in the model is defined as:

$$loss\ ratio = \frac{\text{energy losses in the circuit cables}}{energy\ transported\ by\ those\ circuits}$$

Two loss ratios are used:

- Loss ratio on Imax: this is according formula on energy losses in power cables explained in chapter 3;
- Loss ratio on Iavg: this is according the $P = R.I_{avg}^2$ formula. Formula to calculate the average value see xxxxx

1.1.9.4.1 Estimated residential cable losses

Average annual household consumption in Europe is 3500kWh, resulting in an average power usage of 400 W and an average current of 1.74 A at 230 V. According to MEErP[16] the average floor area for existing residential dwellings (year 2010) is 90 m^2 and 110 m^2 for new residential dwellings.

The assumed residential model consists of one level 1 circuit (RESL1), 2 lighting (RESL2L), 2 socket-outlet (RESL2S) and 2 dedicated circuits (RESL2D). The length of

[13] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/

[14] Ivar GRANHEIM Ivar.Granheim@nexans.com, by mail 20/09/2013,

> *The report motivating the inclusion of power cables in the Working Plan is missing key information to evaluate the effective potential saving of power cables, and assumptions are not robust. A more complete technical study is needed.*

[15] http://www.erp4cables.net/node/6, this questionnaire was sent to installers on the 30th of September, 2013 in the context of this study.
[16] MEErP 2011 Methodology Part 2 , chapter 6.5, edition 28 November 2011

the circuits in the model is about 30 m for the cat 1 circuit and 17 to 20 m for the other circuits. The total amount of conductor material (copper) used in this model is 25 kg/100m^2. It is assumed that the phases are in balance (no current through neutral conductor in case of 3-phase circuit).

Table 1-7: Residential model: parameters and calculated losses (Note: these values are updated in later chapters)

Summary	Circuits					Installation
	RESL1	RESL2L	RESL2S	RESL2D	RESL2D	
Total circuit length (m)	30	34	40	17	17	
CSA (mm²)	10	1.5	2.5	2.5	6	
Loaded cores	3	2	2	2	2	
Kd (distribution factor)	1.00	0.50	0.50	1.00	1.00	
LF (load factor = Pavg/S = Iavg/Imax)	0.03	0.01	0.02	0.01	0.01	
Kf (load form factor)	1.08	1.29	2.83	6.48	4.90	
PF (power factor)	0.90	0.90	0.90	0.90	0.90	
loss ratio on Imax	0.15%	0.02%	0.09%	0.21%	0.06%	0.24%
loss ratio on Iavg	0.12%	0.02%	0.03%	0.03%	0.01%	0.15%

The loads used for the RESL2D circuits are a washing machine and an induction cooker.

Most of the losses are in the level 1 circuit and in the dedicated circuits. Due to the low load factor the losses are rather small (see Table 1-7).

1.1.9.4.2 Estimated service sector cable losses

An average office[17] of 400m² is used with about 33 employees, and an annual energy usage of 166666 kWh. The model consists of one level 1 circuit (SERL1), lighting (SERL2L), socket-outlet (SERL2S) and dedicated (SERL2D) circuits. The length of the circuits in this model is about 30 to 35 m according the results of the enquiry[18]. The total amount of conductor material (copper) used in this model is about 96 kg/100m^2. It is assumed that the phases are in balance (no current through neutral conductor in case of 3-phase circuit).

[17] http://www.entranze.eu/, http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/Scope%20for%20energy%20and%20CO2%20savings%20in%20EU%20through%20BA_2013-09.pdf The scope for energy and CO2 savings in the EU through the use of building automation technology.

[18] http://www.erp4cables.net/node/6, this questionnaire was sent to installers on the 30th of September, 2013 in the context of this study.

Table 1-8: Services model: parameters and calculated losses(Note: these values are updated in later chapters)

Summary	Circuits					Installation
	SERL1	SERL2L	SERL2S	SERL2D	SERL2D	
Total circuit length (m)	50	258	155	57	57	
CSA (mm²)	95	1.5	2.5	25	35	
Loaded cores	3	2	2	3	3	
Kd (distribution factor)	1.00	0.50	0.50	1.00	1.00	
LF (load factor = Pavg/S = Iavg/Imax)	0.36	0.12	0.25	0.12	0.10	
Kf (load form factor)	1.08	1.06	1.23	1.06	1.43	
PF (power factor)	0.90	0.90	0.90	0.90	0.90	
loss ratio on Imax	1.67%	0.38%	0.68%	0.63%	0.61%	2.26%
loss ratio on Iavg	1.39%	0.32%	0.50%	0.53%	0.38%	1.83%

The electrical losses in this electrical installation defined by the parameters listed in Table 1-8 are about 2.26% of the total transported electricity consumed by the loads.

1.1.9.4.3 Estimated industry sector cable losses

In the industry sector and in most cases in the services sector the electrical installation network is designed and worked out by means of an integrated calculation software tool. The IEC recommends a maximum voltage drop at the connection terminals of the electric load (the end point of the circuit) of 3% for lighting circuits and 5 %for other circuits, when supplied from public voltage distribution (see Table 1-16). The recommended limits for installations when supplied from private LV power supplies are even higher (6% for lighting circuits, 8% for other circuits). Consider that this is a recommendation (presented in an informative annex of standard IEC 60634-5-52) and only provides some guidance to designers. In some countries the IEC recommendations are in fact legal requirements, while in other countries similar requirements can be included in local legislation.

Based upon the following assumptions:

- designers use the above mentioned recommendation to design the electrical installation;
- in general the loads in the industry have a rather high load factor;
- most of the energy is transported via dedicated circuits with a high distribution factor (limited number of terminals/loads per dedicated circuit);

one can conclude that:

- the losses in cables in the electrical installation in the industry sector will be between 1% and 8%.

A loss ratio of 2% mentioned in 1.1.9.3.3 is plausible. The following tasks will continue to estimate this loss ratio.

1.1.9.4.4 Summary of estimated cable losses

Looking at the results in the previous sections the calculated losses are in line with the average result of about **2% losses** for electrical installations **in the services and**

industry sector, concluded in the EGEMIN study[19]. The calculated losses in the residential sector, however, are much lower (less than 0.3% compared to 2%). This can be explained by the following reasons:

- The circuits in the residential buildings are in general much shorter than the circuits in the services or industry sector. This is also confirmed by the results of the questionnaire to the installers. Only in multi-dwellings the level 1 circuits can be considerably long and can contribute significantly to the losses in the electrical installation in residential dwellings.
- The load profile (load factor and load form factor) in the residential and non-residential sector differ a lot. In the residential sector the load factor is rather low and the load form factor can be rather high. In the non-residential sector the load profile is more evenly, but with a higher average load per circuit. Again, in general the level 1 circuit in the residential sector also has a higher average load.

Most of the installers (75%) that responded to the enquiry[20] estimated that the losses in the electrical installation vary between 1% and 3%. The others (25%) estimated a loss of less than 1%.

1.1.9.5 Improvement potential by increasing the cross sectional area of the cable

The Egemin study[21] estimated that cable losses could be reduced from 2% up to **0.75%** (see Table 1-9) when applying the **economic** strategy. The study formulated four alternative strategies based on increased conductor cross-sections:

- One size up (S+1) strategy: selection of 1 standard calibre size up from the base line;
- Two sizes up (S+2) strategy: selection of 2 standard calibre sizes up from the base line;
- Economic optimum strategy: a cost minimisation algorithm is run balancing the cost represented by the energy losses over a 10 year investment horizon and the cost for initial purchase and installation of the cables;
- Energy loss minimisation (carbon footprint minimisation) strategy: a minimisation algorithm is run balancing the CO_2 equivalent of the energy losses over a 20 year lifetime horizon and the CO_2 equivalent of copper production for the cables copper weight.

Table 1-9: Impact on energy losses and copper usage (averaged over all models)[21]

Strategy	Energy loss	Loss reduction	Cu weight	Additional Cu
Base	2.04%	0.00%	100.0%	0.0%
S+1	1.42%	0.62%	141.6%	41.6%
S+2	1.02%	1.02%	197.7%	97.7%
Economic	0.75%	1.30%	274.2%	174.2%
Carbon	0.29%	1.76%	907.3%	807.3%

[19] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/

[20] http://www.erp4cables.net/node/6, this questionnaire sent to installers on the 30th of September, 2013 in the context of this study.

[21] "Modified Cable Sizing Strategies, Potential Savings" study,Egemin Consulting for European Copper Institute, May 2011)

The averaged energy loss in power cables in this study was estimated at 2.04 % and the losses can be reduced to 0.75% (loss reduction of 1.3%) applying the economic strategy to the design of the electrical installation (see Table 1-9).

The potential savings are calculated on the basis of the building annual renewal rate[22], as indicated in the table below. The older installations maintain the conventional losses pattern.

Table 1-10: Improvement scenario power cables[23]

Potential savings (starting measures in 2013)	Unit	2010	2015	2020	2025	2030
annual rate (refurbishment)		3%				
Stock of buildings - old standard installations		100%	100%	85%	70%	55%
Stock of buildings - new standard installations		0%	0%	15%	30%	45%
Improvement scenario - final energy consumption	PJprim/year	25182	27045	28277	29907	31012
Savings	PJprim/year	0	0	55	117	182
Total electricity savings	TWh/year	0	0	6	13	20

182 PJ/year of primary energy savings are forecasted by 2030 if the 'improved product' is applied in electrical installations in buildings as of 2015, which corresponds to 20 TWh/year of electric energy savings (see Table 1-10).

Review of the improvement potential

In Annex 1-B another approach is used to calculate the improvement potential of a S+x scenario, independent of a specific model. For each CSA the improvement is calculated based upon the physical parameters. Independent of the amount of cable or the CSA used, one can conclude that a S+1 scenario will reduce losses with minimum 17% and maximum 40% (see Table 1-11). The exact savings in between the minimum and maximum are determined by the amount of cable per cross-sectional areas and the cross-sectional areas of the installed cables.

[22] The refurbishment rate has been set at 3% following the rationale applied for thermal insulation products. Stakeholder Eurocopper applied higher refurbishment rates, but these have been amended to better reflect historic refurbishment rates

[23] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/

Table 1-11 S+x scenario overview based upon CSA ratio (Note: these values are updated in later chapters)

CSA (S)	resistance reduction based upon CSA ratio (S+x)/S				
mm²	S+1	S+2	S+3	S+4	S+5
Minimum	17%	33%	48%	58%	67%
Maximum	40%	63%	76%	85%	91%
Average	27%	47%	61%	71%	78%
Average for CSA 1,5 till CSA 10	38%	61%	74%	83%	89%
Average for CSA 1,5 till CSA 25	36%	58%	72%	81%	86%

For instance when cables with a cross-area section of 1.5 mm² till 10 mm² are used in an electrical installation, opting for a S+1 upsizing strategy would on average reduce the power losses in the installed cables by 38% and by 61 % for the S+2 strategy, by 74% for the S+3 strategy and so on.

A reduction in losses from 2.04% to 0.75% (reduction of 1,3%) implies a resistance reduction of 63%. A scenario consisting of a combination of S+2 and S+3 strategies corresponds with such a resistance reduction.

1.1.9.6 Other improvement potential options

There are other options for lowering losses in electrical installations, e.g. reducing the load per circuit with parallel cables. These options are briefly touched in Annex 1-B and will be researched in detail in Task 4 of this report.

1.1.9.7 Conclusion from the first screening

Important note: the input data and outcomes of the first screening are used with the sole purpose to narrow the scope, they will be reviewed in later tasks.

There is a significant environmental impact.
The losses in power cables, based upon an average loss ratio of 0.3 % in the residential sector and 2% in the non-residential sector, result in an annual loss in power cables of **3.5 TWh** (0.3 % of 1177 TWh) **in the residential sector** in 2030 and **45.8 TWh** (2% of 1329+960 TWh) **in the non-residential sector in 2030, or a total of 49.3 TWh**. Even when the residential sector would be taken out of the equation, this would still mean a loss of about **46 TWh/year** in 2030.

There is significant potential for improvement.
The calculations above proof that a modified sizing strategy, S+2 will reduce the losses by 33% to 63%. With a penetration of 45 % of buildings with an electrical installation according the S+2 strategy in 2030, this would mean an overall reduction of losses in power cables by 15% to 28%. This is equal to annual savings between 7.3 TWh and 14 TWh in 2030. The maximum estimated potential **savings** with S+2 are **in between 0.5 TWh and 1 TWh in the residential secto**r and **in between 6.8 TWh and 13.0 TWh in the non-residential sector** per year. A S+1 strategy in this case (S+1

strategy not applied in the residential buildings sector and 45% penetration) would result in annual savings between 3.5 TWh and 8.24 TWh in 2030. An overview can be found in Table 1-12.

Table 1-12: Overview annual savings in 2030 (Note: these values are updated in later chapters)

		Unit	Residential sector	Services sector	Industry sector	Total	Total without residential sector
Energy consumption		TWh/y	1177	960	1329	3466.00	2289
Loss ratio		%	0.3%	2.0%	2.0%		
Losses		TWh/y	3,531	19.2	26.58	49.31	45.78
Improvement scenario penetration in 2030		%	45%	45%	45%		
S+1 strategy minimum savings	17%	TWh/y	0.27	1.47	2.03	3.77	3.50
S+1 strategy maximum savings	40%	TWh/y	0.64	3.46	4.78	8.88	8.24
S+2 strategy minimum savings	33%	TWh/y	0.52	2.85	3.95	7.32	6.80
S+2 strategy maximum savings	63%	TWh/y	1.00	5.44	7.54	13.98	12.98

There is a significant trade and sales volume.
An annual sales volume of 924 kTon copper in EU for power cables in 2030 is equal to a volume of 103820 m³ copper or an equivalent of 69213 km single core cable with a conductor CSA of 1.5 mm² or 346 km single core cable with a conductor CSA of 300 mm². At a price of 5.3 Euro/kg cable 924 kTon results in 4897 million Euro annual sales. PRODCOM statistics lists for the NACE code 27321380 "Other electric conductors, for a voltage <= 1000 V, not fitted with connectors" in 2012 for the EU28 a production of 2128 kTon and a production value of 12300 million Euro.

Losses in the residential sector are low and also the potential for environmental is low.
Losses in the residential sector are estimated at 3.351 TWh (Table 1-12) and also the improvement potential (0.27-1 TWh). Also cable loading can vary strongly between installation circuits. Non-residential it is also proposed not to focus in residential installation because the improvement potential is low (<> 2 TWh).

Conclusion on eligibility and scope:
Power cables installed in in the service and industry sector meet the criteria for "eligible" products imposed by article 15 of ecodesign directive 2009/125/EC.
Power cables installed in the residential sector do not meet the criteria for "eligible" products imposed by article 15 of ecodesign directive 2009/125/EC.
Ecodesign requirements will apply to power cables when they are placed on the market.
When the cables are placed on the market, it is not known in which sector the power cables will be used and therefore residential cables should be in the scope of Tasks 1, 2

and 7 (partly) but not for Tasks 3-6 on environmental improvement potential.

1.2 Measurements/test standards

1.2.1.1 Relevant standards

Different types of EN documents are available:

- Standards (EN-xxxxx): The EN-50000 to -59999 covers CENELEC activities and the EN-60000 to -69999 series refer to the CENELEC implementation of IEC documents with or without changes.
- Technical Reports (TR): A Technical Report is an informative document on the technical content of standardization work. Only required in one of the three official languages, a TR is approved by the Technical Board or by a Technical Committee by simple majority. No lifetime limit applies.
- Harmonization Documents (HD): Same characteristics as the EN except for the fact that there is no obligation to publish an identical national standard at national level (may be done in different documents/parts), taking into account that the technical content of the HD must be transposed in an equal manner everywhere.

The most relevant standards for this study are explained in the following paragraphs.

1.2.1.1.1 EN 13601:2002 Copper and copper alloys - Copper rod, bar and wire for general electrical purposes

This European Standard specifies the composition, property requirements including electrical properties, and tolerances on dimensions and form for copper rod, bar and wire for general electrical purposes.
Cross-sections and size ranges are:

- round, square and hexagonal rod with diameters or widths across-flats from 2 mm up to and including 80 mm;
- rectangular bar with thicknesses from 2 mm up to and including 40 mm and widths from 3 mm up to and including 200 mm;
- round, square, hexagonal and rectangular wire with diameters or widths across-flats from 2 mm up to and including 25 mm, as well as thicknesses from 0.5 mm up to and including 12 mm with widths from 1 mm up to and including 200 mm.

The sampling procedures, the methods of test for verification of conformity to the requirements of this standard and the delivery conditions are also specified.

Annex A of this standard describes a general grouping of copper into 4 types:

- Tough pitch coppers (i.e. oxygen-containing coppers);
- Oxygen-free coppers;
- Deoxidized coppers;
- Silver-bearing coppers.

The main grade of copper used for electrical applications such as building wire, motor windings, cables and busbars is electrolytic tough pitch copper CW004A (Cu-ETP) which is at least 99.90% pure and has an electrical conductivity of at least 100% IACS minimum. Tough pitch copper contains a small percentage of oxygen (0.02 to 0.04%). If the high conductivity copper is to be welded or brazed or used in a reducing atmosphere, then the more expensive oxygen free high conductivity copper CW008A (Cu-OF) may be used[24].

An important electrical parameter for this study is the electrical conductivity of the copper wire, expressed in [MS/m] or Mega Siemens per meter. A derived unit is the electrical resistivity, expressed in [μΩ/m]. The minimum electric conductivity values for the different copper alloys are defined in Table 3 of the standard.

Notes:

- Copper having an electrical conductivity of 58 MS/m at 20°C (which corresponds to a volume resistivity of 0.01724 μΩ x m at 20°C) is defined as corresponding to a conductivity of 100% IACS (International Annealed Copper Standard);
- Cu-ETP(CW004A) corresponds to E-Cu58 (DIN), Cu-a1 (NF), C101 (BS), C11000 (ASTM)…

1.2.1.1.2 EN 13602:2002 Copper and copper alloys. Drawn, round copper wire for the manufacture of electrical conductors

This European Standard specifies the composition, property requirements including electrical properties, and dimensional tolerances for drawn round copper wire from 0.04 mm up to and including 5.0 mm for the manufacture of electrical conductors intended for the production of bare and insulated cables and flexible cords.
This standard covers plain or tinned, single or multiline, annealed or hard drawn wire. It does not include wire for enamelling (winding wire, magnet wire), for electronic application and for contact wire for electric traction. The sampling procedures, the methods of test for verification of conformity to the requirements of this standard and the delivery conditions are also specified.

1.2.1.1.3 IEC 60502-1: Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) - Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)

This standard specifies the construction, dimensions and test requirements of power cables with extruded solid insulation for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV) for fixed installations such as distribution networks or industrial installations. This standard includes cables which exhibit properties of reduced flame spread, low levels of smoke emission and halogen-free gas emission when exposed to fire.
Cables for special installation and service conditions are not included, for example cables for overhead networks, the mining industry, nuclear power plants (in and around the containment area), submarine use or shipboard application

For this study only the cables with a rated voltage U_0/U (U_m) of 0.6/1 (1.2kV) are considered. Whereas:

- U_0 is the rated voltage between conductor and earth or metallic screen for which the cable is designed;
- U is the rated voltage between conductors for which the cable is designed;
- Um is the maximum value of the "highest system voltage'' for which the equipment may be used (see IEC 60038).

[24] See: http://www.copperinfo.co.uk/alloys/copper/

The conductors in the scope of this standard shall be either of Class 1 or Class 2 of plain or metal-coated annealed copper or of plain aluminium or aluminium alloy, or of Class 5 of plain or metal-coated copper in accordance with IEC 60228.

The types of insulating compounds covered by this standard are listed in table xxx

Table 1-13: Insulating compounds

Insulating compound	Abbreviated designation
a) *Thermoplastic*	
Polyvinyl chloride intended for cables with rated voltages $U_0/U \leq 1{,}8/3$ kV	PVC/A*
b) *Cross-linked:*	
Ethylene propylene rubber or similar (EPM or EPDM)	EPR
High modulus or hard grade ethylene propylene rubber	HEPR
Cross-linked polyethylene	XLPE

* Insulating compound based on polyvinyl chloride intended for cables with rated voltages U_0/U = 3,6/6 kV is designated PVC/B in IEC 60502-2.

The oversheath material shall consist of a thermoplastic compound (PVC or polyethylene or halogen free) or an elastomeric compound (polychloroprene, chlorosulfonated polyethylene or similar polymers). Halogen free sheathing material shall be used on cables which exhibit properties of reduced flame spread, low levels of smoke emission and halogen free gas emission when exposed to fire.

1.2.1.1.4 EN 60228: Conductors of insulated cables

EN 60228 specifies standardized nominal cross-section areas from 0.5 mm^2 to 2 000 mm^2, numbers and diameters of wires and resistance values of conductors in electric cables and flexible cords.

Conductors are divided into four classes

- Class 1: solid conductors;
- Class 2: stranded conductors;
- Class 5: flexible conductors;
- Class 6: flexible conductors which are more flexible than class 5.

The maximum DC resistance of conductor at 20°C is defined for each Class and each nominal cross sectional area for circular annealed, plain and metal-coated copper conductors and aluminium (alloy) conductors.

A table of temperature correction factors kt for conductor resistance to correct the measured resistance at t °C to 20°C is also included.

The measurement of conductor resistance is explained in Annex A of the standard: The measurement must be done on complete length of cable or on a sample of at least 1 meter in length. The conductor resistance at the reference temperature of 20°C is calculated with the following formula:

$$R20 = (Rt \cdot Kt \cdot 1000)/L$$

Where

Kt= temperature correction factor;
R20= conductor resistance at 20°C, in Ω/km;
Rt= measured conductor resistance, in Ω;
L= length of the cable (sample), in m.

Remark:
The maximum resistance of the conductor (Ω/km) is the most important specification related to the energy losses in the power cable. An accurate measurement method to determine this resistance is therefore essential. Nevertheless some important requirements are missing in the measurement method described in Annex A of IEC 60228, such as:

- The maximum allowed uncertainty of the measurement equipment (resistance-, length- and temperature measurement equipment);
- The temperature conditions of the test room;
- The time needed for temperature stabilisation of the test sample.

The above mentioned requirements are defined in IEC 60468:" Method of measurement of resistivity of metallic materials", but this standard is only applicable to solid (non-stranded=Class 1) metallic conductor and resistor material. The maximum allowed over-all uncertainty for the routine measurement method for resistance per unit length is ± 0.4%. IEC 60228 doesn't refer to this standard.

Table 1-14: Maximum resistance of class 1 solid conductors (IEC 60228:2004)

Nominal cross-sectional area (S)	Circular, annealed copper conductors		Aluminium and aluminium alloy conductors, circular or shaped
	Plain	Metal coated	
mm²	Ω/km	Ω/km	Ω/km
0.5	36	36.7	-
0.75	24.5	24.8	-
1	18.1	18.2	-
1.5	12.1	12.2	-
2.5	7.41	7.56	-
4	4.61	4.7	-
6	3.08	3.11	-
10	1.83	1.84	3.08
16	1.15	1.16	1.91
25	0.727	-	1.2
35	0.524	-	0.868
50	0.387	-	0.641
70	0.268	-	0.443
95	0.193	-	0.32
120	0.153	-	0.253
150	0.124	-	0.206
185	0.101	-	0.164
240	0.0775	-	0.125
300	0.062	-	0.1
400	0.0465	-	0.0778
500	-	-	0.0605
630	-	-	0.0469
800	-	-	0.0367
1000	-	-	0.0291
1200	-	-	0.0247

Note: Due to low resistance values for the higher nominal cross-section areas, accurate resistance measuring equipment is needed specially in case of short cable samples (1….5 m). E.g. A 10 mm² class 1 plain annealed copper conductor has a resistance of 1.83 Ω/km, for a sample length of 1 meter this is 0.00183 Ω or 1.83 m Ω.

1.2.1.1.5 EN 50525-1:2011 Electric cables - Low voltage energy cables of rated voltages up to and including 450/750 V (U0/U) - Part 1: General requirements

The EN 50525 (series) standards supersede HD 21.1 S4:2002 and HD 22.1 S4:2002.

This European Standard gives the general requirements for rigid and flexible energy cables of rated voltages U0/U up to and including 450/750 Vac, used in power installations and with domestic and industrial appliances and equipment.

Important NOTE in this standard (Note 3): National regulations may prescribe additional performance requirements for cables that are not given in the particular requirements. For example for buildings with high levels of public access, additional fire performance requirements may be applicable.

The test methods for checking conformity with the requirements are given in other standards, e.g. EN 50395: Electric test methods and EN 50396: Non-electrical test methods.
The particular types of cables are specified in EN 50525-2 (series) and EN 50525-3 (series). The individual parts within those two series are collectively referred to hereafter as "the particular specifications". Only the sizes (conductor class, cross-sectional area), number of cores, other constructional features and rated voltages given in the particular specification apply to the individual cable type. The code designations of these types of cables are in accordance with HD 361.

Notes: National standards conflicting with EN 50525-1 have to be withdrawn on 2014-01-17

1.2.1.1.6 EN HD 21.1 S4: Cables of rated voltages up to and including 450/750V and having thermoplastic insulation – Part1: General requirements - Superseded by EN 50525-1:2011

This harmonized document applies to rigid and flexible cables with insulation and sheath, if any, based on thermoplastic materials, of rated voltages Uo/U up to and including 450/750V, used in power installations.
HD 21.1 S4 specifies the marking of the cable and extension leads, the core identifications, general requirements for the construction of the cables (conductors and insulation) and requirements for the electrical and non-electrical tests for the thermoplastic insulation materials

Note: HD 21.1 S4 is related to IEC 60227-1:1993 "Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 – Part 1: General requirements", but is not directly equivalent.
(Remark: IEC 60227-1993 and the amendment 1 and 2 is replaced by IEC 60227-1: 2007.)

HD 21.1 S4 defines for instance other types of insulation materials in comparison to IEC 60227-1:2007. HD 21.1 S4 defines types TI 1, TI 2, TI 4, TI 5 and TI 6 for conductor insulation material, whereas IEC 60227-1 defines Type PVC/C (fixed installation), PVC/D (flexible cables) and PVC/E (heat resistance cables).

1.2.1.1.7 EN HD 22.1 S4 "Cables of rated voltages up to and including 450/750V and having cross linked insulation – Part1: General requirements" - Superseded by EN 50525-1:2011

Note: HD 22.1 S4 is related to IEC 60245-1:1994 "Rubber insulated cables: Rated voltages up to and including 450/750V – Part 1: General requirements", but is not directly equivalent.

1.2.1.1.8 HD 60364-1:2008 Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions

Harmonized Document 60364-1 (IEC 60364-1) gives the rules for the design, erection, and verification of electrical installations. The rules are intended to provide for the safety of persons, livestock and property against dangers and damage which may arise in the reasonable use of electrical installations and to provide for the proper functioning of those installations.

IEC 60364-1 applies to the design, erection and verification of electrical installations such as those of

a) residential premises;
b) commercial premises;
c) public premises;
d) industrial premises;
e) agricultural and horticultural premises;
f) prefabricated buildings;
g) caravans, caravan sites and similar sites;
h) construction sites, exhibitions, fairs and other installations for temporary purposes;
i) marinas;
j) external lighting and similar installations;
k) medical locations;
l) mobile or transportable units;
m) photovoltaic systems;
n) low-voltage generating sets.

IEC 60364-1 covers

a) circuits supplied at nominal voltages up to and including 1 000 Vac or 1 500 V d.c.;
b) circuits, other than the internal wiring of apparatus, operating at voltages exceeding 1 000 V and derived from an installation having a voltage not exceeding 1 000 Vac, for example, discharge lighting, electrostatic precipitators;
c) wiring systems and cables not specifically covered by the standards for appliances;
d) all consumer installations external to buildings;
e) fixed wiring for information and communication technology, signalling, control and the like (excluding internal wiring of apparatus);
f) the extension or alteration of the installation and also parts of the existing installation affected by the extension or alteration.

The different types of system earthing are explained in paragraph 312.2 of the standard. The system earthing configuration is expressed by a 2 letter combination. The first letter gives the relationship of the power system to earth:

- T= direct connection of one point to the earth
- I= all live parts isolated from earth, or one point connected to earth through a high impedance

The second letter gives the relationship of the exposed-conductive parts of the installation to earth:

- T= direct electrical connection of exposed-conductive-parts to earth, independently of the earthing of any point of the power system
- N= direct electrical connection of the exposed-conductive-parts to the earthed point of the power system.

The following system earthing configurations are most common:

1. **TN systems,** with some additional configurations:
    - TN-S (Separated, neutral conductor and earth conductor are separated);
    - TN-C (Common: neutral conductor and earth conductor are common);
    - TN-C-S (Common-Separated: in a first part of the installation the neutral and earth conductor are common in a second part of the installation they are separated. After separation they must remain separated!).

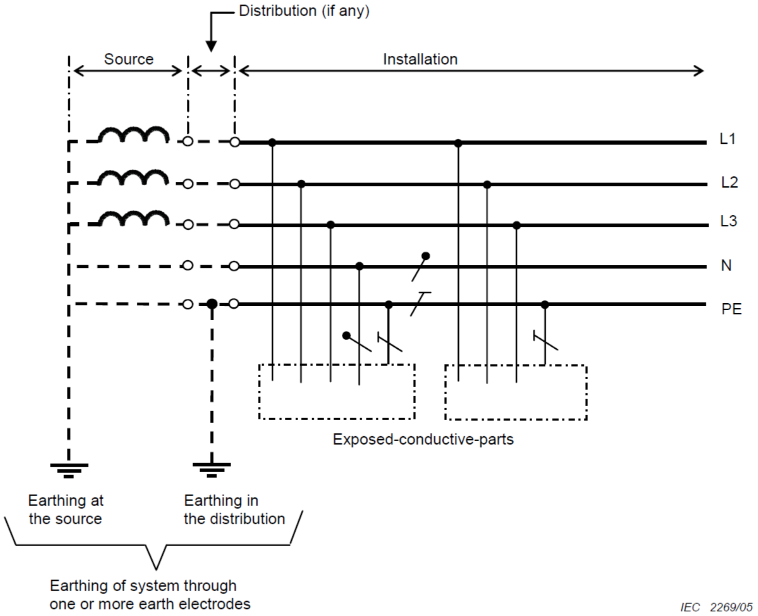


Figure 1-8: TN-S system with separate neutral conductor and protective conductor throughout the system

2. TT systems

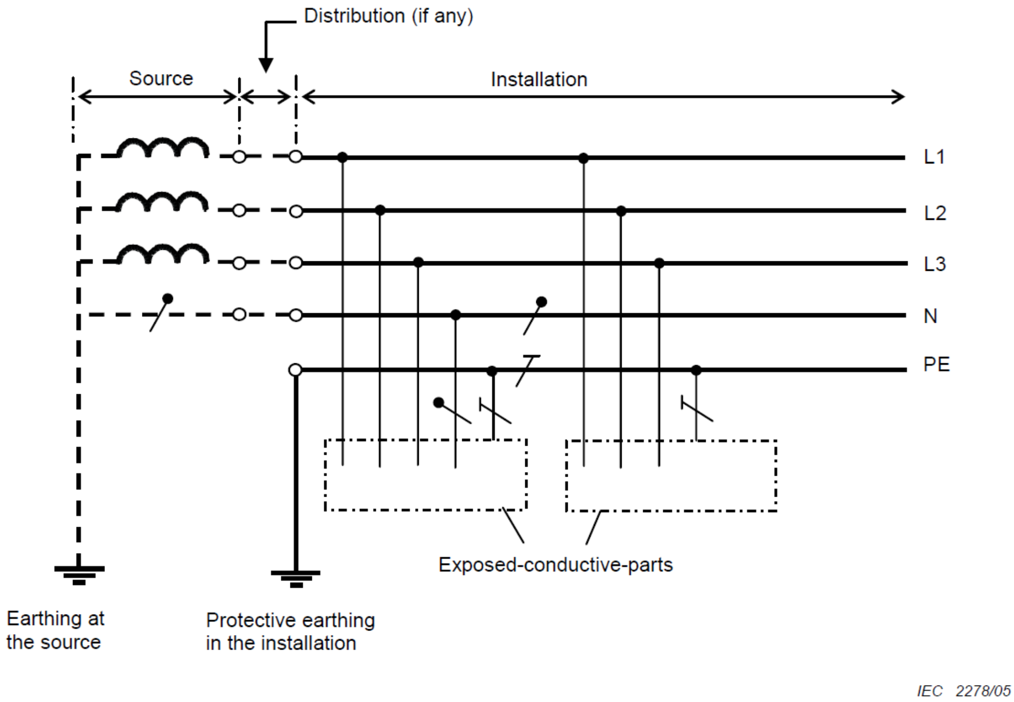


Figure 1-9: TT system with separate neutral conductor and protective conductor throughout the installation

3. IT systems

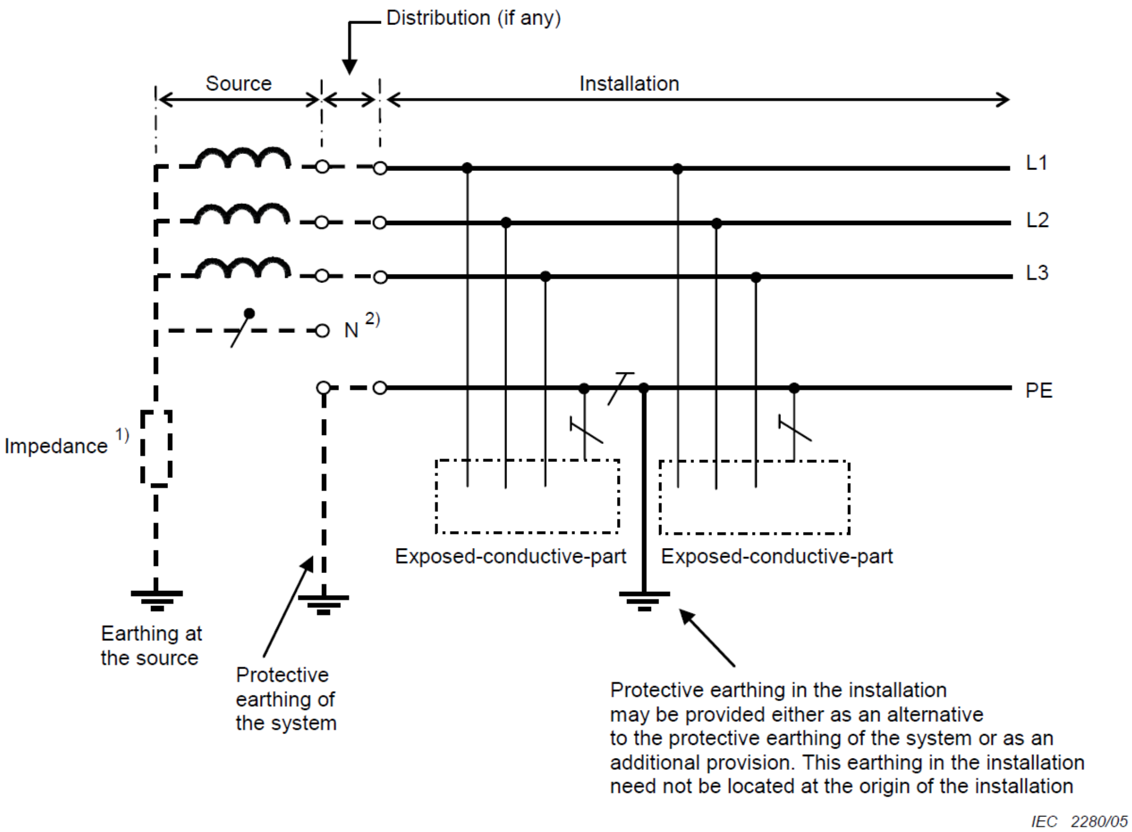


Figure 1-10: IT system with all exposed-conductive-parts interconnected by a protective conductor which is collectively earthed.

1.2.1.1.9 HD 60364-5-52:2011: Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems

IEC 60364-5-52:2009 contains requirements for:

- Selection and erection of wiring systems in relation to external influences, such as:
  - Ambient temperature (AA);
  - Presence of water (AD) or high humidity (AB);
  - Presence of solid foreign bodies (AE);
  - …

- Determination of the current-carrying capacities which depends on:
  - Maximum operating temperature of the insulation material (PVC: 70°C, XLPE: 90°C..);
  - The ambient temperature (Reference temperature is 30°C, the current-carrying capacity decreases with increasing temperatures);
  - The method of installation (examples of methods of installation are defined in the Annex of the standard);
  - The amount of single core or multi core cables grouped (in e.g. a cable tray).

This standard also defines the minimum cross-sectional area of conductors (see Table 1-15)

Table 1-15: HD 60364-5-52:2011 minimum cross-sectional area

Type of wiring system		Use of the circuit	Conductor	
			Material	Cross-sectional area mm²
Fixed Installations	Cables and insulated conductors	Power and lighting circuits	Copper	1,5
			Aluminium	To align with cable standard IEC 60228 (10 mm²) (see note 1)
		Signalling and control circuits	Copper	0,5 (see note 2)
	Bare conductors	Power circuits	Copper	10
			Aluminium	16
		Signalling and control circuits	Copper	4
Connections with flexible insulated conductors and cables		For a specific appliance	Copper	As specified in the relevant IEC standard
		For any other application		0,75[a]
		Extra-low voltage circuits for special applications		0,75

NOTE 1 Connectors used to terminate aluminium conductors should be tested and approved for this specific use.

NOTE 2 In signalling and control circuits intended for electronic equipment a minimum cross-sectional area of 0,1 mm² is permitted.

NOTE 3 For special requirements for ELV lighting see IEC 60364-7-715.

NOTE 4 In the UK, 1,0mm² cable is allowed for use in lighting circuits.

NOTE 5 In the UK 1,0 mm² copper cable is allowed for fixed installations utilizing cables and insulated conductors for power and lighting circuits.

[a] In multi-core flexible cables containing 7 or more cores, NOTE 2 applies.

The minimum cross-sectional area for conductors used in fixed installations is 1.5 mm² for copper and 10 mm² (!) for aluminium, as mentioned in Table 1-15. In the UK 1.0mm² copper cable is allowed for fixed installations utilizing cables and insulated conductors for power and lighting circuits (see Note 5).
Remark: In IEC 60228 there are no specifications defined for Aluminium conductors smaller than 10mm².

Special attention is needed for dimensioning the cross-sectional area of the neutral conductor (paragraph 524.2). In applications (e.g. IT infrastructure) where the third harmonic and odd multiples of third harmonic currents are higher than 33%, total harmonic distortion, it may be necessary to increase the cross-sectional area of the neutral conductor. In some cases the cross sectional area of the neutral conductor has to be dimensioned on 1.45xIb of the line conductor.

The informative Annex G of the standard determines maximum Voltage drop values for consumers' installations. The voltage drop is defined as the voltage difference between the origin of an electrical installation and any load point (see Table 1-16 for voltage drop values for lighting and other uses)
This annex is informative so in fact not obligatory.

Table 1-16: Voltage drop values for lighting and other uses

Type of installation	Lighting %	Other uses %
A – Low voltage installations supplied directly from a public low voltage distribution system	3	5
B – Low voltage installation supplied from private LV supply[a]	6	8
[a] As far as possible, it is recommended that voltage drop within the final circuits do not exceed those indicated in installation type A. When the main wiring systems of the installations are longer than 100 m, these voltage drops may be increased by 0,005 % per metre of wiring system beyond 100 m, without this supplement being greater than 0,5 %. Voltage drop is determined from the demand by the current-using equipment, applying diversity factors where applicable, or from the values of the design current of the circuits.		

The higher these voltage drop values the higher the energy losses in the cable *(e.g. for a resistive load a voltage drop of 5% is equal to an energy loss of 5%).*

Annex I of the standard contains an overview of deviations and/or additional requirements at member state level.

1.2.1.1.10 HD 361 S3:1999/A1:2006 System for cable designation

This Harmonisation Document details a designation system for harmonized power cables and cords, of rated voltage up to and including 450/750 V. (see Table 1-17)

Table 1-17: Cable designation system

Symbol	**Relationship of Cable to Standards**
H	Cable conforming with harmonised standards
A	Recognised National Type of cable listed in the relevant Supplement to harmonised standards
Symbol	**Value, Uo/U**
01	=100/100V; (<300/300V)
03	300/300V
05	300/500V
07	450/750V
Part 2 of the Designation	
Symbol	**Insulating Material**
B	Ethylene-propylene rubber
G	Ethylene-vinyl-acetate
J	Glass-fibre braid
M	Mineral
N	Polychloroprene (or equivalent material)

N2	Special polychloroprene compound for covering of welding cables according to HD 22.6
N4	Chlorosulfonated polyethylene or chlorinated polyethylene
N8	Special water resistant polychloroprene compound
Q	Polyurethane
Q4	Polyamide
R	Ordinary ethylene propylene rubber or equivalent synthetic elastomer for a continuous operating temperature of 60ºC
S	Silicone rubber
T	Textile braid, impregnated or not, on assembled cores
T6	Textile braid, impregnated or not, on individual cores of a multi-core cable
V	Ordinary PVC
V2	PVC compound for a continuous operating temperature of 90ºC
V3	PVC compound for cables installed at low temperature
V4	Cross-linked PVC
V5	Special oil resistant PVC compound
Z	Polyolefin-based cross-linked compound having low level of emission of corrosive gases and which is suitable for use in cables which, when burned, have low emission of smoke
Z1	Polyolefin-based thermoplastic compound having low level of emission of corrosive gases and which is suitable for use in cables which, when burned, have low emission of smoke

Symbol	**Sheath, concentric conductors and screens**
C	Concentric copper conductor
C4	Copper screen as braid over the assembled cores

Symbol	**Sheath, concentric conductors and screens**
D	Strain-bearing element consisting of one or more textile components, placed at the centre of a round cable or tributed inside a flat cable
D5	Central heart (non strain-bearing for lift cables only)
D9	Strain-bearing element consisting of one or more metallic components, placed at the centre of a round cable or distributed inside a flat cable

Symbol	**Special construction**
No Symbol	Circular construction of cable
H	Flat construction of “divisible” cables and cores, either sheathed or non-sheathed
H2	Flat construction of “non-divisible” cables and cores
H6	Flat cable having three or more cores, according to DH 359 or EN 50214
H7	Cable having a double layer insulation applied by extrusion
H8	Extensible lead

Symbol	**Conductor material**
No Symbol	Copper
-A	Aluminium

Symbol	Conductor form
-D	Flexible conductor for use in arc welding cables to HD 22Part 6 (flexibility different from Class 5 of HD 383)
-E	Highly flexible conductor for use in arc welding cables to HD22 Part 6 (flexibility different from Class 6 of HD 383)
-F	Flexible conductor of a flexible cable or cord (flexibility according to Class 5 of HD 383)
-H	Highly flexible conductor of a flexible cable or cord (flexibility according to Class 6 of HD 383)
-K	Flexible conductor of a cable for fixed installations (unless otherwise specified, flexibility according to Class 5 of HD 383)
-R	Rigid, round conductor, stranded
-U	Rigid round conductor, solid
-Y	Tinsel conductor

Part 3 of the Designation

Symbol	Number and size of conductors
(number)	Number, n of cores
X	Times, where a green/yellow core is not included
G	Times, when a green/yellow core is included
(number)	Nominal cross-section, s, of conductor in mm²
Y	For a tinsel conductor where the cross-section is not specified

NOTE The use of the system for Recognised National Types of cable or cord has been withdrawn by CENELEC TC 20. For non-harmonised cables of rated voltage up to and including 450/750 V, National Committees are permitted to use any designation that does not conflict with this HD.

The designation codes of these National normalized cables are defined in national standards, e.g. in Germany according to DIN VDE xxxx, in France according to UTE NF Cxxxx, in Belgium according to NBN xxxx, etc...

1.2.1.1.10 HD 604 S1 1994: 0,6/1 kV and 1,9/3,3 kV power cables with special fire performance for use in power stations

HD 604 applies to rigid and flexible conductor cables for fixed installations having a rated voltage Uo/U of 0.6/1 kV or 1.9/3.3 kV. The insulation and sheaths may be mainly intended for use in power generating plants and sub-stations. All cables have specific fire performance requirements.
Note: The HD 604 cables can also be used in other applications such as residential and industrial electrical installations.

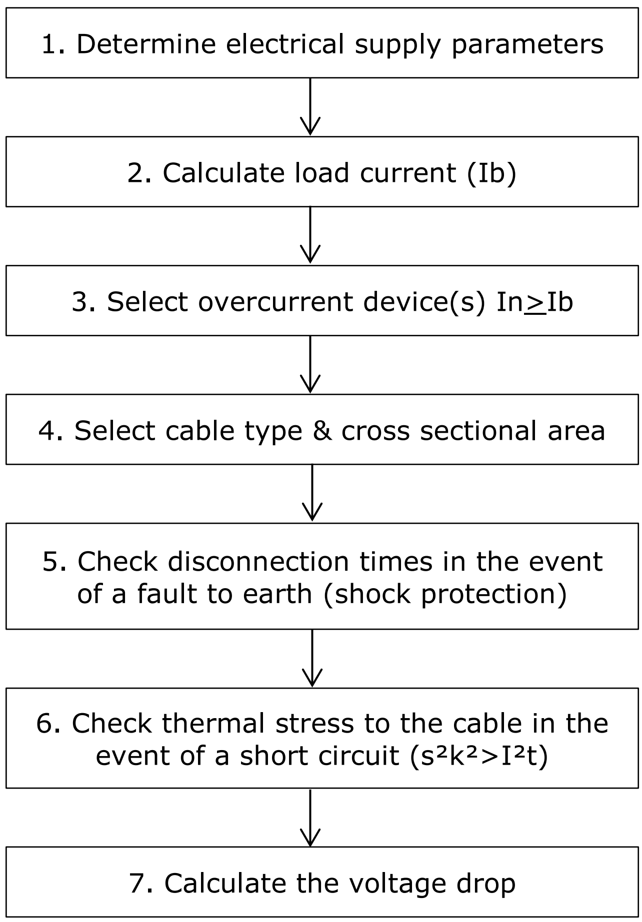
1.2.1.1.11 TR 50480 Determination of cross-sectional area of conductors and selection of protective devices

This Technical Report applies to low-voltage installations with a nominal system frequency of 50 Hz in which the circuits consist of insulated conductors, cables or busbar trunking systems. It defines the different parameters used for the calculation of the characteristics of electrical wiring systems in order to comply with rules of HD 384/HD 60364.

Remarks:

1. This Technical Report is also applicable for checking the compliance of the results of calculations performed by software programs for calculation of cross-sectional area of insulated conductors, cross-sectional area of cables and characteristics for selection of busbar trunking systems with HD 384/HD 60364.
2. Effects of harmonics currents are not covered by this document.
3. The NORMAPME User Guide for European SME's on CENELEC TR 50480 describes the design procedure for an electric circuit. The procedure is summarized in the flow diagram below:

Figure 1-11: Design procedure for an electric circuit



1.2.1.1.12 IEC 60287-1-1 Electric cables – Calculation of the current rating –Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General

Applicable to the conditions of steady-state operation of cables at all alternating voltages, and direct voltages up to 5 kV, buried directly in the ground, in ducts, troughs or in steel pipes, both with and without partial drying-out of the soil, as well as cables in air. The term "steady state" is intended to mean a continuous constant current (100 % load factor) just sufficient to produce asymptotically the maximum conductor temperature, the surrounding ambient conditions being assumed constant. The standard provides formulae for current ratings and losses. The formulae given are essentially literal and designedly leave open the selection of certain important parameters. These may be divided into three groups:

- parameters related to construction of a cable (for example, thermal resistivity of insulating material) for which representative values have been selected based on published work;
- parameters related to the surrounding conditions, which may vary widely, the selection of which depends on the country in which the cables are used or are to be used;
- parameters which result from an agreement between manufacturer and user and which involve a margin for security of service (for example, maximum conductor temperature).

1.2.1.1.13 IEC 60287-3-2 Electric cables - Calculation of the current rating - Part 3-2: Sections on operating conditions - Economic optimization of power cable size

IEC 60287-3-2:2012 sets out a method for the selection of a cable size taking into account the initial investments and the future costs of energy losses during the anticipated operational life of the cable. Matters such as maintenance, energy losses in forced cooling systems and time of day energy costs have not been included in this standard.

For energy efficiency purpose, the most relevant element of the electrical installation is the fixed wiring. The international standard wire sizes are given in the IEC 60228 standard of the International Electro technical Commission.
One important impact on wire size selection for installations comes from the so-called electrical code. In European countries, an attempt has been made to harmonize national wiring standards in an IEC standard, IEC 60364 Electrical Installations for Buildings. Hence national standards follow an identical system of sections and chapters. However, this standard is not written in such language that it can readily be adopted as a national wiring code. As a result many European countries have their own national wiring regulations and/or electrical installation codes, e.g. AREI (Belgium), NFC 15-100 (France), VDE-100 (Germany), BS 7671 (UK), NN1010 (the Netherlands),CEI 64-8 (Italy), etc.

These national regulations can be different from the international and European standards. This means that wiring typology and acronyms are different from country to country as well as the complementary electrical installation code. They have an important impact on cable losses and as requested, an overview of the IEC, European and national standards will be worked out and differences between these standards will briefly be explained in this chapter.

1.2.1.2 Comparative analysis of existing test standards (if applicable)

EN 50395:2005 Electrical test methods for low voltage energy cables

EN 50395 contains electrical test methods required for the testing of harmonized low voltage energy cables, especially those rated at up to and including 450/750 V.

NOTE 1 A description of the origin of these test methods and the background to this European Standard is given in the Introduction and in Annex B. The particular cable standard dictates the tests which need to be performed on the relevant cable type. It also specifies whether the specific test is a type test (T), a sample test (S) or a routine test (R) for the particular cable type.
NOTE 2 T, S and R are defined in the relevant cable standard. The requirements to be met during or after the test are specified for the particular cable type in the relevant cable standard. However, some test requirements are obvious and universal, such as the fact that no breakdown shall occur during voltage tests, and these are stated in the particular test method. Test methods for use specifically in utility power cables are not covered by this European Standard. They can be found in HD 605. Test methods for use specifically in communications cables are the responsibility of the Technical Committee CENELEC TC 46X, Communication cables. At present such test methods are given in EN 50289 series.

Remarks:

- Reference is made to Annex A of EN 60228 for testing the electrical d.c. resistance of conductor (see paragraph 5).
- IEC 60468: "Method of measurement of resistivity of metallic materials" defines a more detailed approach for determining the resistivity of solid metallic conductors compared to the EN 60228 approach

IEC 60364-6: Low-voltage electrical installations – Verification

IEC 60364-6 provides requirements for initial verification, by inspection and testing, of an electrical installation to determine, as far as reasonably practicable, whether the requirements of the other parts of IEC 60364 have been met, and requirements for the reporting of the results of the initial verification. The initial verification takes place upon completion of a new installation or completion of additions or of alterations to existing installations.
This standard also provides requirements for periodic verification of an electrical installation to determine, as far as reasonably practicable, whether the installation and all its constituent equipment are in a satisfactory condition for use and requirements for the reporting of the results of the periodic verification.

1.2.1.3 New standards under development

IEC 60364-8-1 / FprHD 60364-8-1: 2013: Low voltage electrical installation - Part 8-1: Energy efficiency – DRAFT version
This part of IEC 60364 provides additional requirements, measures and recommendations for the design, erection and verification of electrical installations including local production and storage of energy for optimizing the overall efficient use of electricity. It introduces requirements and recommendations for the design of an

electrical installation in the frame of an Energy Efficiency management approach in order to get the best permanent like for like service for the lowest electrical energy consumption and the most acceptable energy availability and economic balance. These requirements and recommendations apply for new installations and modification of existing installations. This standard is applicable to the electrical installation of a building or system and does not apply to products.
Reduction of energy losses in wiring is one of the many design requirements that are mentioned in this draft standard. These losses can be reduced by:

- Reducing the voltage drop in the wiring by reducing the losses in the wiring. Reference is made to IEC 60364-5-52 for recommendation on the maximum voltage drop;
- Increasing the cross sectional area of conductors. Reference is made to IEC 60287-3-2 for an Economic optimization of power cable size;
- Power factor correction to improve the power factor of the load circuit. This will decrease the amount of reactive energy consumption in the cable;
- Reduction of harmonic currents at the load level reduces thermal losses in the wiring.

IEC TR 62125 Environmental statement specific to IEC TC 20 – Electric cables
"Annex A.4 Considerations for use and end of life phase [...] 2) Has information been given to the user on the fact that the choice of transmission/distribution voltage and the conductor cross-section will seriously influence the current transmission losses?"
This TR might evolve into a standard in the years to come (Europa cable)

1.3 Existing legislation

1.3.1 Key methodological issues related to existing legislation

This task identifies and analyses the relevant legislation for the products. It is subdivided in three parts:

Subtask 1 - Legislation and Agreements at European Union level
This section identifies and shortly describes the relevance for the product scope of any relevant existing EU legislation, such as on resource use and environmental impact, EU voluntary agreements and labels.

Subtask 2 - Legislation at Member State level
This section includes a comparative analysis of any relevant existing legislation at Member State level, such as on resource use and environmental impact, voluntary agreements and labels.

Subtask 3 - Third Country Legislation
This section includes a comparative analysis of any relevant existing legislation in third countries, such as on resource use and environmental impact, voluntary agreements and labels.

1.3.1.1 Legislation and Agreements at European Union level

In the regulation and electrical code for electrical wiring in force worldwide, cable sizing is generally a function of the following factors:

- Maximum voltage drop: this criterion is usually decisive when sizing long cables;

- Maximum current in wiring (to avoid cable overheating): this criterion is generally determinative when sizing short cables;
- Temperature of the conductor;
- Emergency or short circuit current rating capacity of the wire;
- Installation mode.

Most of the above criteria were selected on the basis of safety reasons or proper equipment operation concerns, rather than on the basis of an objective of energy loss reduction. For instance, IEC 60364 has requirements for protection against overcurrent, a minimum cable cross section requirement for mechanical strength and a maximum voltage drop. This maximum voltage drop requirement varies according to the ownership of wiring (private vs. public), the end usage (lighting vs. others) and the length of the wire.

The following European directives might be related to the electrical installation/ energy cables within the scope of this study:

- **Directive 89/336/EEC 'Electromagnetic compatibility'**: Energy cables shall be considered as ʼpassive elementsʽ in respect to emission of, and immunity to, electromagnetic disturbances and are as such exempted. Note: Certain accessories may be susceptible to electromagnetic interference ! (IEC 60076-1).

- **Directive 2002/95/EC: Restriction of Hazardous Substances in electrical and electronic equipment**: Cables in the scope of RoHS should be compliant either at the due date of the EEE category they fall in, or in 2019 if not dedicated to any EEE specific category. External cables placed on the market separately that are not part of another electrical and electronic equipment (EEE) must meet the material restrictions and will need their own Declaration of Conformity and CE marking from the relevant date.. The directive is restricted to categories for use with a voltage rating not exceeding 1 000 Volt for alternating current. Cable manufacturers adhere to the European RoHS* directive for electrical materials, and participate to recycle for copper and plastics
- **The Construction Products Regulation (EU) No 305/2011 (CPR)** is replacing the Construction Products Directive (EU) No 89/106/EEC (CPD) since July 1, 2013. CE marking of cables regarding fire performance is mandatory within the CPR and will be possible once all the necessary standards are issued and endorsed by the EC. In order to perform CE-marking a so called harmonized product standard is needed in addition to the test a classification standards. The product standard describes the construction of cable families. The current document is termed Fpr EN 50575: “Power, control and communication cables - Cables for general applications in construction works subject to reaction to fire requirements”.

According to CENELEC JWG M/443 an optimistic scenario would be that CE marking can start by early 2015 and will be obligatory by early 2016 (assuming the minimum default one year transition time)[25]

- **Directive 2006/95/EC 'Low voltage equipment'**: For the purposes of this Directive, ʼelectrical equipmentʽ means any equipment designed for use with a voltage rating of between 50 and 1 000 V for alternating current (and between 75 and 1 500 V for direct current, other than the equipment and phenomena listed in Annex II of the Directive). Please note that LVD is applicable to independent low-voltage equipment placed on EU market which is also used in

[25] Status summary of cable reaction to fire regulations in Europe by SP Technical Research Institute of Sweden & SINTEF NBL Norwegian Fire Research Laboratory

installations, such as control circuits, protection relays, measuring and metering devices, terminal strips, etc. " and thus must carry the CE label.

According to the EU-Commission's guide on the Low Votlage Directive (LVD GUIDELINES ON THE APPLICATION OF DIRECTIVE 2006/95/EC, last modified January 2012); cables (and in general wiring material) is in the scope of the LVD and therefore, must be CE-marked. In addition to the CE-mark, cables will be marked with HAR to increase the tractability. See Annex II of the above mentioned LVD guide.

- **Directive 98/37/EC on the approximation of the laws of the Member States relating to machinery.** The machinery directive is not applicable for power cables as such but may be applicable on certain accessories in the electrical installation.

- **Directive 2002/96/EC on 'Waste Electrical and Electronic Equipment' (WEEE)** is not applicable as power cables are not falling under the categories set out in Annex IA of the directive.

- **Directive 2010/31/EU: Energy Performance of Buildings Directive** and is a revision of Directive 2002/91/EC. Under this Directive, Member States must establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air conditioning systems in buildings. Moreover, the Directive requires Member States to ensure that by 2021 all new buildings are so-called 'nearly zero-energy buildings'.

- **Guidelines** accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework **for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements** (2012/C 115/01). The electrical installation is **not** included in the current guidelines as a cost element to be taken into account for calculating initial investment costs of buildings and building elements.

- REACH is the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals. It entered into force on 1st June 2007. It streamlines and improves the former legislative framework on chemicals of the European Union (EU). This directive is applicable to all the chemical substances that are manufactured and/or marketed in the EU

1.3.1.2 Legislation at Member State level

In general, the national wiring codes of the European countries (see Table 1-18) are based on the IEC 60364 x-xx standards. Most of the European countries have additional national wiring rules. Table 1-20 in Annex 1-A gives an overview of the supply parameters and domestic installation practices from some European countries (Austria, Belgium, Denmark, Germany, Italy, Norway, Spain and United Kingdom)

Table 1-18: EU 28 National wiring codes

Country	National Wiring code
Austria	ÖVE/ÖNORM E8001
Belgium	A.R.E.I/R.G.I.E
Bulgaria	
Croatia (EU28 2013)	
Cyprus	
Czech Republic	
Denmark	Staerkstrombekendtgorelsen 6
Estonia	
Finland	SFS 6000 (based on IEC 60364)
France	NFC 15-100
Germany	VDE 0100
Greece	ELOT HD384
Italy	IEC EN 64-8
Greece	
Hungary	
Ireland	
Italy	CEI 64-8
Latvia	
Lithuania	
Luxembourg	
Malta	
Netherlands	NEN 1010
Poland	
Portugal	UNE 20460
Romania	
Slovakia	
Slovenia	
Spain	UNE 20460
Sweden	SS4364661/ELSÄK-FS 1999:5
UK	BS7671 16° Edition IEE Wiring Regulations

The designation codes of National normalized cables are defined in national standards, e.g. in Germany according to DIN VDE xxxx, in Belgium according to NBN xxxx, etc.

Legislation on environmental aspects:

Environmental Product Declaration (EPD) (source: Europacable):
French decree (2013-1264): The Order related to environmental product declarations for construction and decoration products intended for use in buildings was published in Official Journal No. 0302 from December 29th 2013. It defines the content of environmental declarations and the LCA methodologies and calculation rules applicable (see http://www.developpement-durable.gouv.fr/-La-declaration-environnementale,7322-.html)

The Norwegian legislation on recycling and treatment of Waste (FOR-2004-06-01-930) has a dedicated section for cables (Amendment 1 on Product groups for EE-products and EE-waste – § 12 on cables and wires)

1.3.1.3 Third Country Legislation

Scope:
This section again looks at legislation and measures in Third Countries (extra-EU) that have been indicated by stakeholders as being relevant for the product group.

IMPORTANT NOTICE ON THE DIFFERENCES IN INTERNATIONAL LINE VOLTAGE STANDARDS:
All European and most African and Asian countries use a supply that is within 10% of 230 V at 50 Hz, whereas Japan, North America and some parts of South America use a voltage between 100 and 127 V at 60 Hz.

A number of building energy guidelines, standards or codes go beyond the existing electrical safety and operational requirements by adopting more stringent maximum voltage drop requirements to limit circuit impedance and thereby wiring energy loss. In North America, the "Energy Standard for Buildings Except Low-Rise Residential Buildings" of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE/ IESNA 90.1), as well as the National Energy Code for Buildings of Canada (NECB 2011) are two examples.

1.3.1.4 Voluntary initiatives

The **ELEKTRO+ Initiative** in Germany is designed to assist in the planning and installation of electrical systems in flats and houses. It covers the following areas:
- scope and complexity of the electrical installation,
- safety,
- comfort,
- energy efficiency.

Awareness among building owners and renovators for safer and more energy sustainable electrical installation has been in decline for years. Even in new houses electrical systems are often inadequate for the size of the building and fail to meet minimum standards. There is a shortage of switches, sockets, lighting points, communication devices and electrical circuits.

In older buildings the situation is even more critical. There are approximately 10.6 million occupied housing units in Germany built before 1949. The majority of these still use their original electrical systems which fall well below the needs of today's residents.

The demands of modern household appliances push these old electrical installations to their limits. Residents are often unaware of the dangers. This **overloading** is reflected in the high incidence of household fires; 10 – 15% being caused by the smouldering of electrical cables and through the use of defective appliances.

The inadequate provision of electrical power points in houses leads to **the use of multi-socket connectors and extension leads**. This puts a permanent overload onto the electrical circuits, considerably raising the risk of fire. By providing additional socket-outlets and circuits the cables will be less loaded on average.

The service life of an electrical installation is 40 to 45 years, so the decision to fit an up to date system, meeting modern standards, will have a beneficial effect on the quality and value of the building.

For this reason the **HEA** – Fachgemeinschaft für effiziente Energieanwendung e.V. has been working for decades on the standardisation of electrical systems and has developed, on the basis of the **minimum standard (DIN 18015**), its own set of HEA Electrical Installation Values.

In the interests of ensuring better consumer protection the HEA, together with the Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (ZVEI), founded the ELEKTRO+ Iniative to inform building owners and renovators about planning standards.

The ELEKTRO+ Initiative presents the standards and directives on electrical installation in houses and flats as readily accessible information for planners (architects, consultant electrical engineers and electrical contractors). This information is also designed to help building owners and home buyers to better understand and have a greater say in the planning of their electrical systems.

The ELEKTRO+ Initiative provides objective information for these target groups on the planning and installation of electrical systems both for new buildings and for modernisation projects.

The Approved Cables Initiative in the UK was established in March 2010 to address the issue of unsafe, non-approved and counterfeit cable entering the UK marketplace. With industry and regulator support, the ACI is taking a proactive and hard hitting approach to educate the electrical supply chain – from manufacturers to end users through a comprehensive communication schedule of seminars, marketing material and articles to national trade media**.**

The Product Environmental Profile (PEP) Eco passport (http://www.pep-ecopassport.org/p-e-p-association): is an environmental identity card for electrical and HVAC-R products. It allows the results of a Life Cycle Analysis to be presented appropriately and in accordance with international standards (ISO14025, 14040 and 14044).
The PEP association consists of manufacturers, users, institutional and professional associations. It is responsible for implementing the PEP Eco passport ®, which is recognised as the benchmark for good practices in terms of environmental communication

Some cables manufacturers provide **tools to calculate the economic optimum section** based on the use conditions (Europacable):

A number of software tools (see Table 1-19) exist for the design of electrical installations, some of them offering the possibility to run energy efficiency calculations and potential optimization.

Table 1-19 Non exhaustive list of software tools for the design of electrical installations, providing economic sizing feature or not[26]

Software	Manufacturer	Economic sizing Standard	Economic sizing Optional	Economic sizing External	Remarks
Caneco BT	ALPI Software	No	Partly Investment estimation only	Yes, through export and import to and from external processing (proven)	Modular software, features depend on actual licensed configuration
TR-ciel (legacy) **Elec Calc**	Trace Software	No	Partly Investment estimation only	No clear information on export and import facilities	Features depend on installed options (TR-ciel) Unclear for successor Elec Calc
Kitgoni	Kitgoni SPRL	Yes	/	/	The URE module (Utilisation Rationnelle de l'Energie), is standard included, the user only has to choose to use it.
Simaris design	Siemens	No	No	No	Import & export facilities can be extend through Simaris project software
Ecodial	Schneider Electric	No	No	No	
Solutions Electrical	Solutions Electrical UK	No	Partly Investment estimation only	No	

26 26 http://www.leonardo-energy.org/white-paper/economic-cable-sizing-and-potential-savings

ANNEX 1-A

Table 1-20 is informational only and based upon the NORMAPME user guide[27].

Table 1-20: Supply parameters and domestic installation practices per country[27]

Country	Austria	Belgium	Denmark	Italy	Norway	Spain	United Kingdom
1. Distribution system (of the supplier)	TN-C-S 3% TT	TN-C-S (earth not made available) A little IT, being replaced by TN	The most common system is TT Except for Copenhagen- TN-C-S For large industrial TN-S	Mainly TT (domestic) TN-C-S TN-S for large industrial IT hospitals	Most common: IT without distributed neutral, New residential areas: TN-C-S Some parts of the country: TT without distributed neutral	90% TT	Generally TN-C-S with a little TT
2. Provision of earth by supplier	Yes for TN-C-S (In addition the installation must have its own earthing system)	No Installer must provide, less than 30 (300mA RCD) If greater than 30 100mA RCD	Not for domestic	No for TT	Yes for TN-C-S and most IT and TT (In addition the installer must set up an earthing system)	Not for domestic or small commercial	Legislation requires the supplier to provide an earth terminal unless it is considered inappropriate e.g. Building supplies, farms, domestic swimming pools

[27] NORMAPME User Guide on CENELEC TR 50480

Country	Austria	Belgium	Denmark	Italy	Norway	Spain	United Kingdom
3. Installation system	Most TN-S TT	TT	TT for domestic TN-C-S for commercial/ind ustrial TN-S for large industrial, where they own their transformer-station	TT for domestic TN-C-S for commercial/industri al TN-S for large industrial	Most common: IT (without N) In some parts of the country: TT (without N) Where a new supply transformer is established: TN-C-S	Most common TT (90%)	TN-C-S with a little TN-S and a little TT
4. Demand limits (supply capacity)	Domestic max 60 A Every supply must be able to deliver 18kW	Own transformer for loads greater than 125A	Domestic up to 80A fuse	Domestic 3kW,4,5kW,6kW or 10kW 1Phase+N 230V or 10kW 3Phase 400V Can go to 15kW for 3Phase+N 400V ; increasing in 1kW steps to 30kW with increasing demand charges	Domestic: Most common: 63 A circuit breaker, but this is no absolute limit.	level 1 -3.3kW, level 2 - 5.5kW, level 3 - 12kW min 15A max 63A	Domestic up to 100A

5. Supply Voltage	3 phase and neutral 400/230V , Tolerance +10% -6%	3Phase 230V 3Phase+N 230V 3Phase+N 400V (new installations 3P+N 400V)	3Phase +N 400/230 V Tolerance +/- 10%	3 phase and neutral 400/230V , Legislation requires Tolerance +/-10% Note: Italy the Voltage supply is still 220 /380V for effect of the law 105/1949	IT and TT 230 V TN-C-S 230/400 V Supplier declares limits e.g.= ± 10% No legislation	3 Phase+N 230/400V Tolerance +/- 10%	3 phase and neutral 400/230V , Legislation requires Tolerance +10% -6%
Country	**Austria**	**Belgium**	**Denmark**	**Italy**	**Norway**	**Spain**	**United Kingdom**
6. Allowed voltage drop	legislation1% before meter, 3% in installation (4% for domestic installations) but recommended 1.5%	Proper functioning	4% for all installations	Proper functioning 4%; 1,5% *Mounting column* 2,5%	Legislation: Proper functioning Standard: 3 % for lighting 5 % for others	Domestic 3% lighting 5% power Can be exceeded if total voltage drop	No legislation that is specific Proper functioning For domestic installations
				Internal circuit of flat		from Xfmer less than 9.5%	

7. Legislation	Building regulations have electrical –specific IEC 60364 Not retrospective	Reg Gen for elec installations Royal decree of 1981-specific req for domestic	Building regulations have electrical – specific IEC 60364 Not retrospective	CEI 64-8 ; 700 page doc CEI 0-21 90 page doc	Legislation for electrical installations is general. The Standard is one way of complying. The Standard includes a specific section for dwellings.	Yes specific ref to standard see Electrical rules for low voltage RD 842/2002	General requirement in the Building regulations for domestic electrical installations to be safe.
8. Registration of electrical installer				Chamber of Commerce, DM37/08	Yes		Yes for domestic work
Country	**Austria**	**Belgium**	**Denmark**	**Italy**	**Norway**	**Spain**	**United Kingdom**
Country	**Austria**	**Belgium**	**Denmark**	**Italy**	**Norway**	**Spain**	**United Kingdom**
9. Fault level Maximum at supply	Max 16kA assumed Assumed to be 10kA max at distribution board. In practice fault levels less than 6kA	6kA at supply Predicted to be 3000A	Ik,max = 16 kA cos = 0,3 Assumed to be 6kA max at distribution board (It applies only to household)	Max 6kA for single phase 10kA three phase. 15kA three phase when there is no main-switch on the power supplier	Most common less than 10 kA at the distribution board. The supplier often declares maximum 16 kA and minimum 0.5 kA. No max/min described in the legislation	Max 6kA for single phase 10kA three phase	Supply authorities declare 16kA In practice fault levels less than 6kA

Country	Austria	Belgium	Denmark	Italy	Norway	Spain	United Kingdom
10.Loop impedance Max at supply, (or min fault level)	Max domestic Loop impedance at supply = 0,6Ω Typically 0.3 For TT Ra+Rb less than 100	All TT	and Ik,min = 5 x In cos = 1.	No limits $R_E\ I_{dn} \leq 50V$ 30mA RCD protection	No limits	TT, limit 20+R	Assumed to be 0.35Ω for TN-C-S supplies 0.8 Ω for TN-S 20Ω+R_A for TT
11. Sockets	Schuko Sockets DIN 49440 30mA RCD protection	Except SELV and luminaries, must have earth contact Max 8 per circuit 30mA RCD protection	Sockets must comply with Regulation 107-2-D1 Schuko sockets are not allowed. Only the Danish and French/Belgian systems are allowed	Italian standard 16/10A, Schuko in offices , in kitchen and washing machine	Schuko	Schuko	Must comply with BS 1363 (13A shuttered) or EN 60309-2 Rings are commonly used in all domestic and commercial properties, but radial circuits are allowed and often used. 30mA RCD protection

12. Lighting circuits	Separate Lightning Circuits (2 required) Separate Socket Outlet circuits	Two circuits required Class I luminaires not required to be connected with earth	not separated	New Standard 64-8-V3 September 2011, Level 1,2,3,: Level 1 Separate Lightning Circuits Separate Socket Outlet circuits Level 2 Separate Lightning Circuits (3 required) Separate Socket Outlet circuits Level 3 Separate Lightning Circuits (more than 3 required with automatic control) Separate Socket Outlet circuits	Not separated	Separate required, up to 30 per circuit	It is practice to have separate lighting, socket outlet and heating circuits, but is not a requirement of the standard.
13. Mixed power and lighting circuits	Separated	Allowed, outlets limited to 8	Allowed	Not Allowed	Allowed		Allowed, but generally separated
14. Installation standard used	HD 60364 series Austrian special: ÖVE/ÖNORM E8001		IEC 60- 364 series or “Danish special rules”	Italian standard CEI	IEC 60364 series supplemented by HD 60364/384		IEC 60364 series supplemented by HD 60364/384, published as BS 7671
Country	Austria	Belgium	Denmark	Italy	Norway	Spain	United Kingdom

15. Earthing requirements	Earth electrode required even for TN systems TN: 4.5m vertically 10m horizontal TT: $R_A \leq 100\Omega$.	i) Earth electrode $R_A \leq 100\Omega$ ii) 35 mm^{2}Cu electrode installed In foundations as a loop ii) If $R_A \geq 30\Omega$ separate RCD ($I_{\Delta n}$ 30mA) for lighting and for Each group of 16 sockets	Earth electrode is a requirement for TT incl. protection by RCD in all installations. ($I_{\Delta n}$ 30mA)	TT system No limits $R_E I_{dn} \leq 50V$ With RCD ($I_{\Delta n}$ 30mA)	Separate earth electrode required for all systems. Dwellings supplied from IT and TT:		Mainly TT (domestic) Industrial TN
16. Design(circuit calculations		Not required	Table for Ze: $Ze \quad \frac{U_0}{I_a}$ Ia is interrupted for the time there are set in table 3.	The project required more power to 6kW, size of more 400m2 and Special Environments	Has to verify and document protection against: Overload Short circuit Fault		Simple tables are used for domestic installations specifying cable csa, protective device and cable length (to meet voltage drop, shock and short circuit requirements.
17. Singular National Characteristics				For domestic $I_2 \leq I_z$	For dwellings: $I_2 \leq I_z$		Ringed socket circuits are commonly used in all domestic and commercial properties, but radial circuits are allowed and often used.
Country	Austria	Belgium	Denmark	Italy	Norway	Spain	United Kingdom

18. Lighting circuit polarised				yes			Yes
19. Socket circuit polarised				Yes for wiring Yes for socket terminals			Yes for wiring Yes for socket terminals

ANNEX 1-B

Table 1-14 shows the maximum resistance of conductor at 20 °C according IEC 60228:2004 Table 1 Class 1 solid conductors for single-core and multicore cables.

Based on the values in Table 1-14 the losses in Watt per meter cables (at 20 °C) for current rating of 0,5A till 100A are shown in Table 1-21, Table 1-22 and Table 1-23 respectively for plain circular annealed copper conductors, metal coated circular annealed copper conductors and circular or shaped aluminium and aluminium alloy conductors.

Notes:

- the calculation of the losses ($R.I^2$) in Table 1-21, Table 1-22 and Table 1-23 is made for each section and current rating in the table based upon the values in Table 1-14.The maximum current-carrying capacities are based on Table C.52.1 of IEC 60364-5-52 (Installation method E, XLPE insulation) for copper conductors and on Table B.52.13 of the same standard (Installation method E, XLPE insulation) for aluminium conductors.
- in the calculation of losses in this paragraph the skin effect isn't taken into account. However, when applying a S+x strategy to cables with large diameters (above 400 mm^2 CSA) this gradually becomes important.
- The resistance of a cable increases with the temperature. This is not included in the calculation of losses here. A S+x strategy will result in a lower conductor temperature.

Table 1-21: Losses in W/m for LV cables of class 1: circular, annealed copper conductors: plain

	Circular, annealed copper conductors: plain									
Current (A)	**0.5**	**1**	**2**	**4**	**10**	**16**	**20**	**40**	**64**	**100**
CSA (mm^2)										
0.5	0.009	0.036	0.144	0.576	-	-	-	-	-	-
0.75	0.006125	0.0245	0.098	0.392	2.45	-	-	-	-	-
1	0.004525	0.0181	0.0724	0.2896	1.81	4.6336	-	-	-	-
1.5	0.003025	0.0121	0.0484	0.1936	1.21	3.0976	4.84	-	-	-
2.5	0.001853	0.00741	0.02964	0.11856	0.741	1.89696	2.964	-	-	-
4	0.001153	0.00461	0.01844	0.07376	0.461	1.18016	1.844	7.376	-	-
6	0.00077	0.00308	0.01232	0.04928	0.308	0.78848	1.232	4.928	-	-
10	0.000458	0.00183	0.00732	0.02928	0.183	0.46848	0.732	2.928	7.49568	-
16	0.000288	0.00115	0.0046	0.0184	0.115	0.2944	0.46	1.84	4.7104	11.5
25	0.000182	0.000727	0.002908	0.011632	0.0727	0.186112	0.2908	1.1632	2.977792	7.27
35	0.000131	0.000524	0.002096	0.008384	0.0524	0.134144	0.2096	0.8384	2.146304	5.24
50	9.68E-05	0.000387	0.001548	0.006192	0.0387	0.099072	0.1548	0.6192	1.585152	3.87
70	0.000067	0.000268	0.001072	0.004288	0.0268	0.068608	0.1072	0.4288	1.097728	2.68
95	4.83E-05	0.000193	0.000772	0.003088	0.0193	0.049408	0.0772	0.3088	0.790528	1.93
120	3.83E-05	0.000153	0.000612	0.002448	0.0153	0.039168	0.0612	0.2448	0.626688	1.53
150	0.000031	0.000124	0.000496	0.001984	0.0124	0.031744	0.0496	0.1984	0.507904	1.24
185	2.53E-05	0.000101	0.000404	0.001616	0.0101	0.025856	0.0404	0.1616	0.413696	1.01
240	1.94E-05	7.75E-05	0.00031	0.00124	0.00775	0.01984	0.031	0.124	0.31744	0.775
300	1.55E-05	0.000062	0.000248	0.000992	0.0062	0.015872	0.0248	0.0992	0.253952	0.62
400	1.16E-05	4.65E-05	0.000186	0.000744	0.00465	0.011904	0.0186	0.0744	0.190464	0.465
500	-	-	-	-	-	-	-	-	-	-
630	-	-	-	-	-	-	-	-	-	-
800	-	-	-	-	-	-	-	-	-	-
1000	-	-	-	-	-	-	-	-	-	-
1200	-	-	-	-	-	-	-	-	-	-

Table 1-22: Losses in W/m for LV cables of class 1: circular, annealed copper conductors: metal-coated

	Circular, annealed copper conductors: Metal-coated									
Current (A)	**0.5**	**1**	**2**	**4**	**10**	**16**	**20**	**40**	**64**	**100**
CSA (mm²)										
0.5	0.009175	0.0367	0.1468	0.5872	-	-	-	-	-	-
0.75	0.0062	0.0248	0.0992	0.3968	2.48	-	-	-	-	-
1	0.00455	0.0182	0.0728	0.2912	1.82	4.6592	-	-	-	-
1.5	0.00305	0.0122	0.0488	0.1952	1.22	3.1232	4.88	-	-	-
2.5	0.00189	0.00756	0.03024	0.12096	0.756	1.93536	3.024	-	-	-
4	0.001175	0.0047	0.0188	0.0752	0.47	1.2032	1.88	7.52	-	-
6	0.000778	0.00311	0.01244	0.04976	0.311	0.79616	1.244	4.976	-	-
10	0.00046	0.00184	0.00736	0.02944	0.184	0.47104	0.736	2.944	7.53664	-
16	0.00029	0.00116	0.00464	0.01856	0.116	0.29696	0.464	1.856	4.75136	11.6
25	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-
150	-	-	-	-	-	-	-	-	-	-
185	-	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-	-
300	-	-	-	-	-	-	-	-	-	-
400	-	-	-	-	-	-	-	-	-	-
500	-	-	-	-	-	-	-	-	-	-
630	-	-	-	-	-	-	-	-	-	-
800	-	-	-	-	-	-	-	-	-	-
1000	-	-	-	-	-	-	-	-	-	-
1200	-	-	-	-	-	-	-	-	-	-

Table 1-23: Losses in W/m for LV cables of class 1: Aluminium and aluminium alloy conductors, circular or shaped

	Aluminium and aluminium alloy conductors, circular or shaped									
Current (A)	**0.5**	**1**	**2**	**4**	**10**	**16**	**20**	**40**	**64**	**100**
CSA (mm²)										
0.5	-	-	-	-	-	-	-	-	-	-
0.75	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-
1.5	-	-	-	-	-	-	-	-	-	-
2.5	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-
10	0.00077	0.00308	0.01232	0.04928	0.308	0.78848	1.232	4.928	12.61568	-
16	0.000478	0.00191	0.00764	0.03056	0.191	0.48896	0.764	3.056	7.82336	-
25	0.0003	0.0012	0.0048	0.0192	0.12	0.3072	0.48	1.92	4.9152	12
35	0.000217	0.000868	0.003472	0.013888	0.0868	0.222208	0.3472	1.3888	3.555328	8.68
50	0.00016	0.000641	0.002564	0.010256	0.0641	0.164096	0.2564	1.0256	2.625536	6.41
70	0.000111	0.000443	0.001772	0.007088	0.0443	0.113408	0.1772	0.7088	1.814528	4.43
95	0.00008	0.00032	0.00128	0.00512	0.032	0.08192	0.128	0.512	1.31072	3.2
120	6.33E-05	0.000253	0.001012	0.004048	0.0253	0.064768	0.1012	0.4048	1.036288	2.53
150	5.15E-05	0.000206	0.000824	0.003296	0.0206	0.052736	0.0824	0.3296	0.843776	2.06
185	0.000041	0.000164	0.000656	0.002624	0.0164	0.041984	0.0656	0.2624	0.671744	1.64
240	3.13E-05	0.000125	0.0005	0.002	0.0125	0.032	0.05	0.2	0.512	1.25
300	0.000025	0.0001	0.0004	0.0016	0.01	0.0256	0.04	0.16	0.4096	1
400	1.95E-05	7.78E-05	0.000311	0.001245	0.00778	0.019917	0.03112	0.12448	0.318669	0.778
500	1.51E-05	6.05E-05	0.000242	0.000968	0.00605	0.015488	0.0242	0.0968	0.247808	0.605
630	1.17E-05	4.69E-05	0.000188	0.00075	0.00469	0.012006	0.01876	0.07504	0.192102	0.469
800	9.18E-06	3.67E-05	0.000147	0.000587	0.00367	0.009395	0.01468	0.05872	0.150323	0.367
1000	7.28E-06	2.91E-05	0.000116	0.000466	0.00291	0.00745	0.01164	0.04656	0.119194	0.291
1200	6.18E-06	2.47E-05	9.88E-05	0.000395	0.00247	0.006323	0.00988	0.03952	0.101171	0.247

The resistance of the cable and thus the losses in a circuit can be reduced by using cables with a larger CSA. Table 1-24 shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+1. S+1 is one size up, S+2 two sizes up and S+3 three sizes up. Table 1-25 shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+2. Table 1-26 shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+3.

The resistance of the cable and thus the losses in a circuit can be reduced by using cables with a larger CSA. Table 1-24 shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+1. S+1 is one size up, S+2 two sizes up and S+3 three sizes up. Table shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+2. Table 1-26 shows the reduction in cable resistance when replacing a cable with CSA S by a cable with CSA S+3.

Table 1-24: S+1 scenario

	S+1 resistance reduction		
Nominal cross-sectional area (S)	Circular. annealed copper conductors		Aluminium and aluminium alloy conductors. circular or shaped
	Plain	Metal coated	
mm²			
0.5	32%	32%	-
0.75	26%	27%	-
1	33%	33%	-
1.5	39%	38%	-
2.5	38%	38%	-
4	33%	34%	-
6	41%	41%	-
10	37%	37%	-
16	37%	-	38%
25	28%	-	37%
35	26%	-	28%
50	31%	-	26%
70	28%	-	31%
95	21%	-	28%
120	19%	-	21%
150	19%	-	19%
185	23%	-	20%
240	20%	-	24%
300	25%	-	20%
400	-	-	22%
500	-	-	22%
630	-	-	22%
800	-	-	22%
1000	-	-	21%
1200	-	-	15%

Table 1-25: S+2 scenario

	S+2 resistance reduction		
	Circular. annealed copper conductors		Aluminium and aluminium alloy conductors. circular or shaped
Nominal cross-sectional area (S)	Plain	Metal coated	
mm²			
0.5	50%	50%	-
0.75	51%	51%	-
1	59%	58%	-
1.5	62%	61%	-
2.5	58%	59%	-
4	60%	61%	-
6	63%	63%	-
10	60%	-	61%
16	54%	-	55%
25	47%	-	47%
35	49%	-	49%
50	50%	-	50%
70	43%	-	43%
95	36%	-	36%
120	34%	-	35%
150	38%	-	39%
185	39%	-	39%
240	40%	-	38%
300	-	-	40%
400	-	-	40%
500	-	-	39%
630	-	-	38%
800	-	-	33%
1000	-	-	-
1200	-	-	-

Table 1-26: S+3 scenario

Nominal cross-sectional area (S)	S+3 resistance reduction		
	Circular, annealed copper conductors		Aluminium and aluminium alloy conductors, circular or shaped
	Plain	Metal coated	
mm²			
0.5	66%	67%	-
0.75	70%	70%	-
1	75%	74%	-
1.5	75%	75%	-
2.5	75%	76%	-
4	75%	75%	-
6	76%	-	-
10	71%	-	72%
16	66%	-	66%
25	63%	-	63%
35	63%	-	63%
50	60%	-	61%
70	54%	-	53%
95	48%	-	49%
120	49%	-	51%
150	50%	-	51%
185	54%	-	53%
240	-	-	52%
300	-	-	53%
400	-	-	53%
500	-	-	52%
630	-	-	47%
800	-	-	-
1000	-	-	-
1200	-	-	-

Table 1-27 shows the minimum and maximum resistance reduction for the above mentioned cables. For instance when all class 1 plain copper cables are replaced by plain copper cables with one size up the cables losses will reduce by minimum 19% and maximum 41%.

Table 1-27: S+x scenario overview

	Circular, annealed copper conductors				Aluminium and aluminium alloy conductors, circular or shaped	
	Plain		Metal coated			
Upsizing strategy	Minimum resistance reduction	Maximum resistance reduction	Minimum resistance reduction	Maximum resistance reduction	Minimum resistance reduction	Maximum resistance reduction
S+1	19%	41%	27%	41%	15%	38%
S+2	34%	62%	50%	63%	33%	61%
S+3	48%	76%	67%	76%	47%	72%

Table 1-28: S+x scenario overview based upon CSA ratio

CSA (S)	resistance reduction based upon CSA ratio (S+x)/S				
mm²	S+1	S+2	S+3	S+4	S+5
0.5	33%	50%	67%	80%	88%
0.75	25%	50%	70%	81%	88%
1	33%	60%	75%	83%	90%
1.5	40%	63%	75%	85%	91%
2.5	38%	58%	75%	84%	90%
4	33%	60%	75%	84%	89%
6	40%	63%	76%	83%	88%
10	38%	60%	71%	80%	86%
16	36%	54%	68%	77%	83%
25	29%	50%	64%	74%	79%
35	30%	50%	63%	71%	77%
50	29%	47%	58%	67%	73%
70	26%	42%	53%	62%	71%
95	21%	37%	49%	60%	68%
120	20%	35%	50%	60%	70%
150	19%	38%	50%	63%	70%
185	23%	38%	54%	63%	71%
240	20%	40%	52%	62%	70%
300	25%	40%	52%	63%	70%
400	20%	37%	50%	60%	67%
500	21%	38%	50%	58%	
630	21%	37%	48%		
800	20%	33%			
1000	17%				
1200					
Minimum	17%	33%	48%	58%	67%
Maximum	40%	63%	76%	85%	91%
Average	27%	47%	61%	71%	78%
Average for CSA 1,5 till CSA 10	38%	61%	74%	83%	89%
Average for CSA 1,5 till CSA 25	36%	58%	72%	81%	86%

Assuming cables of section 1.5 mm² till 10 mm² are used in residential houses, opting for a S+1 upsizing strategy would on average reduce the power losses in the installed cables by 38% and by 61 % for the S+2 strategy, by 74% for the S+3 strategy and so on.

Table 1-29: Conductor volume increase based upon CSA ratio

CSA (S)	volume increase based upon CSA ratio				
mm²	S+1	S+2	S+3	S+4	S+5
0.5	50%	100%	200%	400%	700%
0.75	33%	100%	233%	433%	700%
1	50%	150%	300%	500%	900%
1.5	67%	167%	300%	567%	967%
2.5	60%	140%	300%	540%	900%
4	50%	150%	300%	525%	775%
6	67%	167%	317%	483%	733%
10	60%	150%	250%	400%	600%
16	56%	119%	213%	338%	494%
25	40%	100%	180%	280%	380%
35	43%	100%	171%	243%	329%
50	40%	90%	140%	200%	270%
70	36%	71%	114%	164%	243%
95	26%	58%	95%	153%	216%
120	25%	54%	100%	150%	233%
150	23%	60%	100%	167%	233%
185	30%	62%	116%	170%	241%
240	25%	67%	108%	163%	233%
300	33%	67%	110%	167%	233%
400	25%	58%	100%	150%	200%
500	26%	60%	100%	140%	
630	27%	59%	90%		
800	25%	50%			
1000	20%				
1200					
Minimum	20%	50%	90%	140%	200%
Maximum	67%	167%	317%	567%	967%
Average	39%	95%	178%	297%	467%
Average for CSA 1,5 till CSA 6	61%	156%	304%	529%	844%
Average for CSA 1,5 till CSA 25	57%	142%	266%	448%	693%
Average for CSA 10 till CSA 70	46%	105%	178%	271%	386%

Table 1-30: Loss reduction per conductor volume increase

CSA (S)	loss reduction per volume increase				
mm²	S+1	S+2	S+3	S+4	S+5
0.5	67%	50%	33%	20%	13%
0.75	75%	50%	30%	19%	13%
1	67%	40%	25%	17%	10%
1.5	60%	38%	25%	15%	9%
2.5	63%	42%	25%	16%	10%
4	67%	40%	25%	16%	11%
6	60%	38%	24%	17%	12%
10	63%	40%	29%	20%	14%
16	64%	46%	32%	23%	17%
25	71%	50%	36%	26%	21%
35	70%	50%	37%	29%	23%
50	71%	53%	42%	33%	27%
70	74%	58%	47%	38%	29%
95	79%	63%	51%	40%	32%
120	80%	65%	50%	40%	30%
150	81%	63%	50%	38%	30%
185	77%	62%	46%	37%	29%
240	80%	60%	48%	38%	30%
300	75%	60%	48%	38%	30%
400	80%	63%	50%	40%	33%
500	79%	63%	50%	42%	
630	79%	63%	53%		
800	80%	67%			
1000	83%				
1200					
Minimum	60%	38%	24%	15%	9%
Maximum	83%	67%	53%	42%	33%
Average	73%	53%	39%	29%	22%
Average for CSA 1,5 till CSA 6	62%	39%	25%	16%	11%
Average for CSA 1,5 till CSA 25	64%	42%	28%	19%	14%
Average for CSA 10 till CSA 70	69%	49%	37%	28%	22%

Reducing the total length of cable for a circuit

Because the physical location of appliances/loads for a particular installation is fixed, the total length of cable needed in the electrical installation cannot be changed, unless other installation techniques or topologies are used. For instance adding an extra circuit level with additional circuit boards could reduce the total length of cable used in the electrical installation and even shorten the average circuit length of the electrical installation.

The goal is to keep the distances between the main loads and the switch boards (and transformers) as close as possible to minimize energy losses in the electrical wiring. This can be achieved with the "barycentre method": The objective of this method is to set up the transformer and switchboard at a location based on a relative weighting due to the energy consumption of the loads so that the distance to a higher energy consumption load is less than the distance of a lower energy consumption load (see Informative Annex A of FprHD 60364-8-1).

Using a size up strategy combined with a higher circuit load (less circuits) could reduce the total length of the cable in the circuit and the resistance per meter cable, but the load (I) will increase.

Reducing the load per circuit

Peak current load profile – secondary PFP

The power losses are determined by the I^2 factor. Reducing the average current per circuit will reduce the loss exponential. However, reducing the loss per circuit by diminishing the average current per circuit will in fact reduce the average load per circuit. As a result extra circuits have to be added to the installation to serve the same load as before, resulting in larger installed cable lengths.

For instance all the loads of one circuit could be fed over two circuits instead of one. The load (I) per circuit will be lower, but the total length of cable will increase.

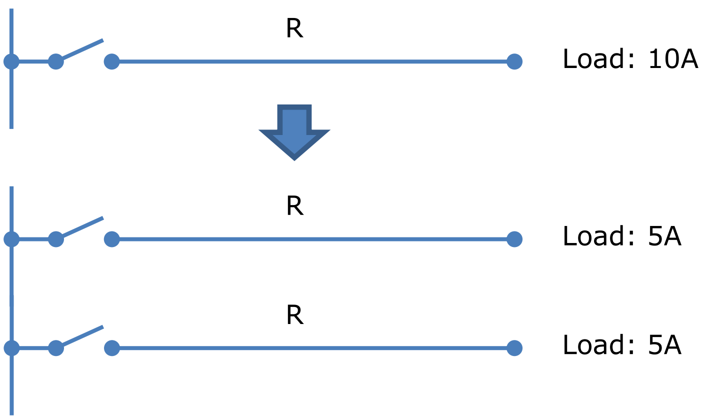


Figure 1-12 example: two parallel circuits instead of one circuit

For instance the losses ($R.I^2$) in Figure 1-12 for scenario with one circuit are $10^2.R = 100.R$, where R is the resistance of the cable in the circuit. For the same load the losses in the second scenario with two parallel circuits of the same length is $5^2.R + 5^2.R = 50.R$. However, when splitting the load (multiple appliances) over two circuits the load should be divided in such a way that appliances consuming simultaneously are split over different circuits; otherwise the losses will remain the same. However, it is not trivial to split loads over different circuits when the load profiles are complex or unknown. Energy management systems in combination with smart plugs or smart appliances (BNAT) could overcome this problem and reduce the peaks in a circuit.

Looking at the installation level this means that losses in an installation can be reduced by balancing loads over different circuits based upon the degree of simultaneity of these loads.

Note: jagged load profiles with a lot of temporary peak (accumulated) currents cause higher losses than more peak shaved load profiles demanding the same amount of energy. Adequate design of circuits and load distribution over the circuits or control mechanisms in energy management systems (or energy management functions in building management systems) in buildings reducing the total energy usage and the peak currents (peak clipping) will therefore diminish the losses in the circuits.