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Contract N°. Specific contract 185/PP/ENT/IMA/12/1110333-Lot8 implementing FC ENTR/29/PP/FC Lot 2

Report

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

Lot 8- Power Cables
DRAFT Task 3 report

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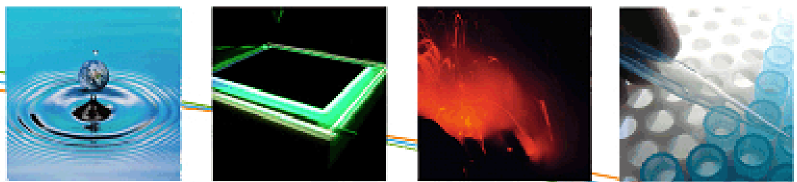

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EXECUTIVE SUMMARY

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 the 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 and 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 Using Products) allows the evaluation of whether and to which extent various energy-using products fulfill 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.

The preparatory phase of this study is to collect data for input in the MEErP model an executive Summary of the complete study will be elaborated at completion of the draft final report.

Comment: This report is currently a working progress, as some parts of the study are missing comments and data from the stakeholders, therefore it shall not be viewed as a full report.

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List of Acronyms

A	Amperage
α_c	Corrected or circuit load factor
AC	Alternating Current
Al	Aluminium
AREI	Algemeen Reglement op de Elektrische Installaties
Avg	Average
B2B	Business–to-business
BAT	Best Available Technology
BAU	Business As Usual
BNAT	Best Not yet Available Technology
CE	Conformite Europee
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
Cu	Copper
DC	Direct Current
DIN	Deutsches Institut für Normung
E	Energy
EC	European Commission
EMC	Electro Magnetic Compatibility
EMI	Electromagnetic Interference
EMS	Energy Management System
EN	European Norm
EOL	End Of Life
EPBD	Energy Performance of Buildings Directive
EPR	Ethylene Propylene Rubber
ErP	Energy related Products
EuP	Energy using Products
EU	European Union
HD	Harmonization Document
HV	High Voltage
IEC	The International Electro technical Commission
IT	Information Technology
K	Kilo (10^3)
Kf	Load form factor
LCA	Life Cycle Assessment
LV	Low Voltage
LVD	Low Voltage Directive
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy using Products
MV	Medium Voltage
NBN	Bureau voor Normalisatie - Bureau de Normalisation
PE	Polyethylene
PF	Power factor
PP	Polypropylene
PRODCOM	PRODuction COMmunautaire
PVC	Polyvinylchloride
R	Resistance
RCD	Residual Current Device
REMODECE	Residential Monitoring to Decrease Energy Use and Carbon Emissions in

	Europe
RES	Renewable Energy Sources
RMS	Root Mean Square
RoHS	Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
S	apparent power
S	Section
SME	Small and Medium sized Enterprise
TBC	To Be Completed
TBD	To Be Defined
TC	Technical Committee
TR	Technical Report
UK	United Kingdom
V	Voltage
VITO	Flemish institute for Technological Research
XLPE	Cross-linked Polyethene
XLPVC	Cross-linked PVC

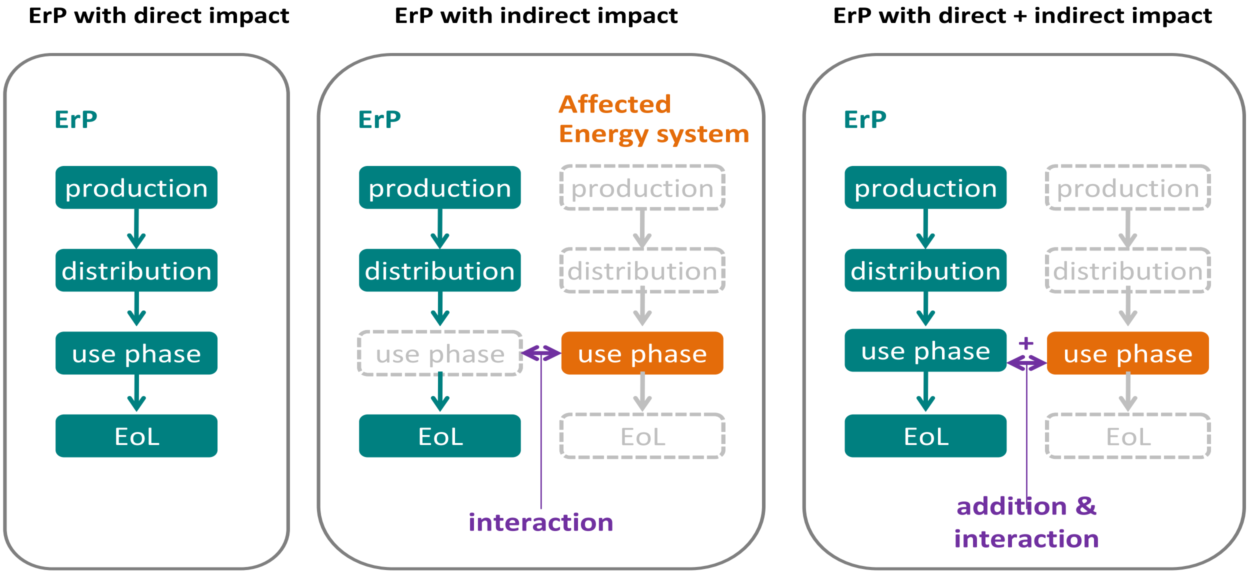
Use of text background colours

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

CHAPTER 3 TASK 3: USERS (PRODUCT DEMAND SIDE)

Objective:User requirements can be influenced by product design and product information. Relevant user-parameters are an important input for the assessment of the environmental impact of a product during its use and end-of-life phase, in particular if they are different from the standard measurement conditions as described in subtask 1.2.

With the recast of the Ecodesign Directive to energy-related products in 2009, the discussion on user requirements needs to take into account the indirect impacts of energy-related products (see illustration below).



Summary of Task 3:
TBC
Comment: This report is currently a working progress, as some parts of the study are missing comments and data from the stakeholders, therefore it shall not be viewed as a full report.

3.1 Systems aspects of the use phase for ErPs with direct impact

The main function of the electrical installation is to transport electricity. The installation consumes energy by fulfilling this function, because the transport experiences electrical resistance in different parts of the installation and part of the energy is dissipated as heat energy. In this study the focus is on the power cable used in the electrical installation. The power cable is part of the electric circuit. The electric circuit consists of different segments using power cables, junction boxes, terminal connections and protection equipment like circuit breakers limiting the maximum current in the power cable. The electrical installation consists of several circuits, distribution boards/system board, and overall protection devices. The electrical installation is an indispensable part of modern buildings.

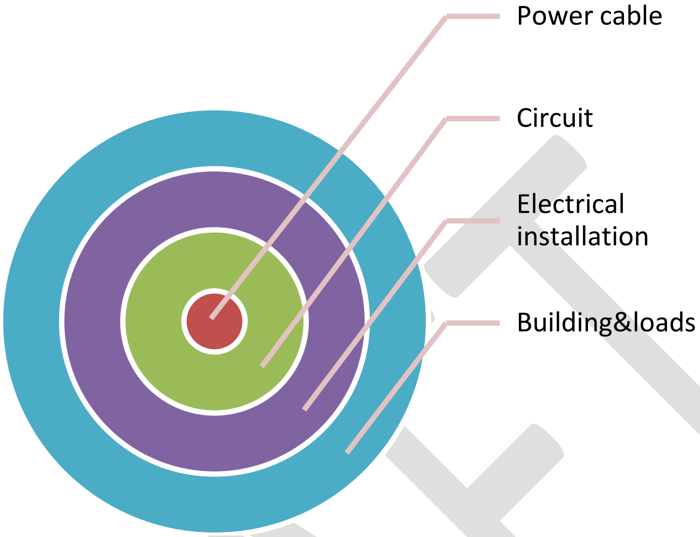


Figure 3-1: From strict product to systems approach

The use of the power cable is mainly defined by the characteristics of the circuit, the load distribution in the building and the profile of the loads (in time).

3.1.1 Definition of the User and context

For electrical installation it is important to discriminate between different types of users who use cables:

1. The engineering company or architect of the electrical installation.
2. The person or organisation performing the actual installation of electrical installation of a new building or renovation of parts of the building. e.g. electrical contractors, interior designers, property developers and installers, hereafter called the *'installers'.* The installer is responsible for putting into service the electrical installation including the power cables..
3. The person or organisation responsible or certifying the electrical installation, hereafter called the *'certifier'.*
4. The end-user who lives or works in the building and makes use of the electrical installation, hereafter called the *'user'*.
5. The owner of the building and thus of the electrical installation, hereafter called the *'owner'*. The owner finances the electrical installation and has the end-responsibility for the electrical installation in the building (certification, safety

coordinator,..?). Depending on the sector and function type of the building the owner and user roles may be unified in one organisation/person.

Depending on the sector and country the installer and user can be the same acting as a Do-It-Yourself (DIY) consumer. In some countries the installer can also perform the certification of a (small) installation. The DIY method however is only applied in the residential building sector.

3.1.2 Loss parameters directly related to the cable itself

As discussed in task 1 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:

$$R = \rho_t . l/A \text{ (Ohm)}$$

The losses in a power cable are therefore affected by:

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

In annex B of task 1 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.

3.1.2.1 Conductor material electrical resistance

Both aluminium and copper are used as conductors and are available for use in standard wire sizes and foils. Aluminium is less used in cables with small CSAs.

Table 3-1: Properties of Aluminium and Copper

Property	Aluminium	Copper
Electrical Resistivity (relative)	0.61	1
Thermal Conductivity(Cal/s.cm.K)	0.57	0.94
Relative weight for the same conductivity	0.54	1
Cross section for the same conductivity	1.56	1
Tensile Strength kg/cm²	844	2250
Spefific weight (kg/dm³)	2.7	8.9
Electrical Resistivity (mOhm.mm) (20°C)	26.5	16.7
Thermal coefficient of resistance (1e-6/K)	3770	3900

3.1.2.2 Cross-sectional area (CSA)

The available CSAs for power cable are defined by standardisation and are expressed in mm². The following values for cross-sectional area are used in IEC 60228:2004: 0,75; 1; 1,5; 2,5; 4; 6; 10; 16; 25; 35; 50; 70; 95; 120; 150; 185; 240; 300; 400; 500; 630; 800; 1000 and 1200 mm².

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

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

The selection of the appropriate cable cross sectional area takes into account specific parameters like :

- requested current-rating capacity by the circuit;
- length of the cable in the circuit;
- maximum allowed voltage drop;
- installation conditions (ambient temperature and heat dissipation);
- maximum operating temperature for cables and the full installation;
- safety fuses, circuit breakers and short circuit time;
- number of cables per circuit.

Table 3-2: Typical cable cross sectional areas depending on the circuit type

Sector	Circuit application type	CSA (mm²) min	CSA (mm²) ref	CSA (mm²) max
Residential	Distribution circuit	2.5	10	16
	Lighting circuit	1	1.5	2.5
	Socket-outlet circuit	1.5	2.5	6[1]
	Dedicated circuit	2.5	4	6
Services	Distribution circuit	10	35	600
	Lighting circuit	1.5	1.5	2.5
	Socket-outlet circuit	1.5	2.5	6
	Dedicated circuit	2.5	35	95
Industry	Distribution circuit	25	95	600
	Lighting circuit	1.5	1.5	2.5
	Socket-outlet circuit	1.5	2.5	10[2]
	Dedicated circuit	2.5	35	600

[1] 5G6 mm² cable at 3-phase 400Vac and max 3% voltage drop results in maximum circuit length of 132m and Imax of 16A or maximum circuit length of 53m and Imax of 40A.

[2] 5G10 cable at 3-phase 400Vac and max 3% voltage drop results in maximum circuit length of 142m and Imax of 25A or maximum circuit length of 56m and Imax of 63A.

Conclusion:

3.1.2.3 Length of cable

The length of cable is primarily determined by the physical topography and design of the building, the buildings' function type and the placing of the appliances along the building. The length of cable used in the electrical installation is also determined by the topology of the electrical installation. For instance an installation can have one or more distribution levels.

Conclusion:
See data on lengths of cables in electrical circuits in section 3.1.4.5.

3.1.2.4 Number of cores

A power cable contains one or more conductor cores. When the cable is placed in conduits multiple single-core cables can be used. Some products consists of a combination of singe-core or multicore cable and flexible conduits. The number of cores is determined by:

- The AC grid system (TT,TN,IT), see Task 1
- Single phase or three-phase system
- Earthing conductor included or not, neuter conductor included or not
- Also the handling of the cable (multi-core cables with large CSAs are more difficult to handle than multiple single-core cables) and the product availability/existence play a role in cable selection.

The cores in a cable generally have the same CSA, but can also have different CSA. The phase currents in three phase systems tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor or even to leave it out in the ideal situation.

3.1.2.5 Skin effect

The 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, and decreases with greater depths in the conductor. It has an effect on the cable resistance and is partly determined by the used conductor material and CSA of the cable. 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.

$$\delta = \sqrt{2\rho/\omega\mu}$$

Where

ρ = resistivity of the conductor
ω = angular frequency of current = 2π × frequency
μ = absolute magnetic permeability of the conductor

At 50 Hz in copper, the skin depth δ is about 9,2 mm. For aluminium it is about 11,6 mm.

The skin effect is only relevant for cables with a diameter D much larger than the skin depth. Using a material of resistivity ρ we then find the AC resistance of a wire of length L to be:

$$R \approx L\rho/(\pi(D-\delta))$$

At 50 Hz the skin effect is negligible for cables with a CSA of less than 400 mm². For cables with a very large CSA the skin effect is an important factor. For instance for cables with a CSA of 1000 mm² the AC resistance compared to the DC resistance will increase with almost 30% for copper and 14 % for aluminium. Figure 3-2 shows the increase in resistance for copper and aluminium conductors at 50Hz for CSAs from 400 mm² till 1200 mm².

A S+x strategy for cables with a CSA of more than 400 mm² will therefore be countered by the increasing resistance due to the skin effect. Looking at material use versus savings the strategy will become less efficient for cables with a very large CSA.

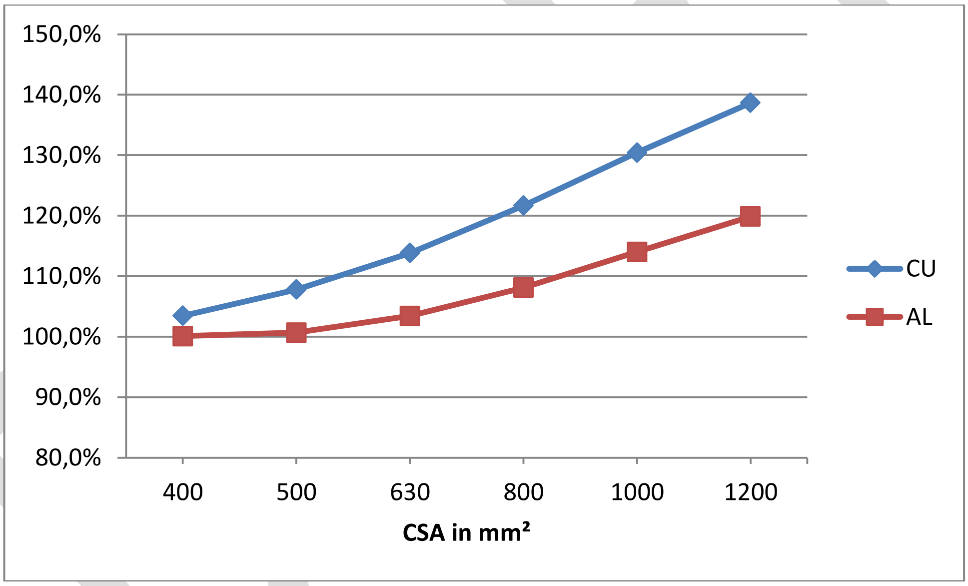


Figure 3-2: Resistance increase due to skin effect at 50Hz for CU and AL conductors

Conclusion:
The skin effect is only relevant for power cables with very large CSA. From 400 mm² on the effect is noticeable, and becomes relevant for CSAs more than 630 mm². To be confirmed if these cables with CSA above 400 mm2 are relevant in buildings.

3.1.3 Other functional cable parameters not directly related to losses

3.1.3.1 Insulation material

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

The selection of insulation material is also influenced by building properties and function of the building (risk of fire, evacuation capability,..). For instance in Belgium the national code AREI imposes requirements on power cables regarding flame resistance. For buildings higher than 25 meter, schools, hospitals and so on the evacuation velocity is one of the factors determining the flame resistance category (elapsed time).

Conclusion:
To be decided whether this is relevant or not.

3.1.3.2 Construction of the conductor

The type of construction mainly has an effect on the flexibility/bending radius. The selection of the type of construction is thus largely determined by the flexibility and bending requirements.

The construction type has also a small effect on the AC resistance of the cable. Table 3-3 shows the influence of the construction type on the maximum resistance at 20° C, based upon the resistance values for different CSAs and classes, listed in IEC 60228:2004. ΔR stands for the R_{classx} – R_{class1}. $\Delta R/R_{class1}$ indicates the amount of resistance reduction or increase for class x compared to class1.

Table 3-3: Construction type versus maximum resistance (at 20° C)

	Class 1 solid conductors for single-core and multicore cables	Class 2 stranded conductors for single-core and multi-core cables		Class 5 flexible copper conductors for single-core and multi-core cables		Class 6 flexible copper conductors for single-core and multi-core cables	
CSA	Plain	Plain wires	ΔR/Rclass1	Plain wires	ΔR/Rclass1	Plain wires	ΔR/Rclass1
mm²	Ω/km	Ω/km	%	Ω/km	%	Ω/km	%
0,5	36	36	0,0%	39	8%	39	8%
0,75	24,5	24,5	0,0%	26	6%	26	6%
1	18,1	18,1	0,0%	19,5	8%	19,5	8%
1,5	12,1	12,1	0,0%	13,3	10%	13,3	10%
2,5	7,41	7,41	0,0%	7,98	8%	7,98	8%
4	4,61	4,61	0,0%	4,95	7%	4,95	7%
6	3,08	3,08	0,0%	3,3	7%	3,3	7%
10	1,83	1,83	0,0%	1,91	4%	1,91	4%
16	1,15	1,15	0,0%	1,21	5%	1,21	5%
25	0,727	0,727	0,0%	0,78	7%	0,78	7%
35	0,524	0,524	0,0%	0,554	6%	0,554	6%
50	0,387	0,387	0,0%	0,386	0%	0,386	0%
70	0,268	0,268	0,0%	0,272	1%	0,272	1%
95	0,193	0,193	0,0%	0,206	7%	0,206	7%
120	0,153	0,153	0,0%	0,161	5%	0,161	5%
150	0,124	0,124	0,0%	0,129	4%	0,129	4%
185	0,101	0,0991	-1,9%	0,106	5%	0,106	5%
240	0,0775	0,0754	-2,7%	0,0801	3%	0,0801	3%
300	0,062	0,0601	-3,1%	0,0641	3%	0,0641	3%
Average			-0,4%		5,6%		5,6%

Conclusion:
To be decided whether this is relevant or not.

3.1.4 Loss parameters directly related to the electrical circuit and network topology

Losses are also related to the electrical circuit and network topology.
An electrical circuit starts at a distribution board and consists of a protective device, cable, junction boxes and distribution endpoints all being part of the electrical circuit.
Also the network topology has an impact, which are the relative positions and the interconnections of the circuit elements representing an electric circuit.
In the following sections parameters are defined and reference data is included to model relevant parameters related to cable losses.

To be completed with an example electrical circuit single wire diagram and electrical floor plan drawing.

3.1.4.1 Single phase or three phase circuit

Being a single or three phase circuit has mainly an effect on the number of cores of the cable (or number of single core cables) used in the circuit. A single phase circuit cable will have two cores (phase and neuter) or three cores (phase, neuter, earthing). A three phase circuit cable canl have three cores (three phases), four cores (phases and earthing, phases and neuter) or five cores (phases, neuter, earthing).

The voltage used in the single phase system is 230V.
The voltage used in the three phase system can be 230VAC or 400VAC, depending the configuration. To transport the same energy in a three phase 400V system as in a single phase 230 V system the current can be reduced and hence losses are lower. High power loads in the service sector and industry, i.e. above 4600 VA (230VAC/20A), are therefore most often connected 400 VAC three phase.

Conclusion:
In this study we will assume that all loads above 4600 VA are connected three phase, a sensitivity analysis in Task 7 could check for a single phase 230 VAC.
Lighting circuits and socket outlet circuits will be considered single phase.
Three phase socket outlet or connector circuits do exist and will be reconsidered in a sensitivity analysis in Task 7.

3.1.4.2 Maximum voltage drop in a circuit

The maximum voltage drop in a circuit (see Figure 3-3) is determined in standard (IEC 60364-5-52 – informative Annex G), see task 1. The voltage drop is directly proportional to the power loss.

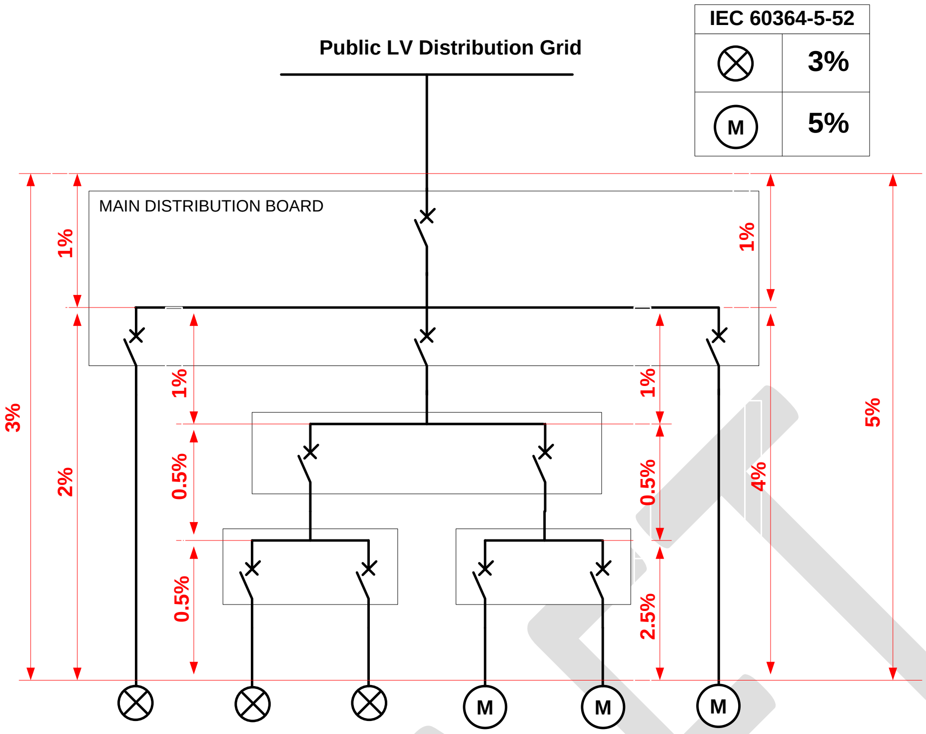


Figure 3-3: Voltage drop in an electrical installation

3.1.4.3 Overcurrent protection in a circuit

Cable losses are limited because the maximum current or overcurrent is limited in an electrical circuit by using circuit breakers or fuses, as discussed in Task 1.
The overcurrent device rating (In) is selected so that In is greater than or equal to the load current (Ib). Ib is the design current of the circuit, i.e. the current intended to be carried by the circuit in normal service (see task 1).

Circuit breakers are installed according to standard IEC 60364-1.

TBC

3.1.4.4 Circuit network topology

Electrical circuits can be installed in various network topologies.

In lighting circuits three different topologies are common:

- A 'Bus network topology' approach, e.g. this is most often implemented with a so-called DALI[3] bus where a control signal is distributed together the power cable. This is frequently used in large industrial installations. Typically a five wire cable is used (5G1.5) whereby two wires are used for the control signal.
- 'Two-wire installation' that contains only one wire between switch and lamp. In this system the switch/control product is connected in series with lamp/load and

[3] http://www.dali-ag.org

the neutral is not present in the switch (except in some countries). The advantage is the low amount of required copper wire and reduced short circuit risk during installation but the disadvantage is that no direct power supply is available for electronic control switches (e.g. dimmers). In Figure 3 3 an example of a 'two wire installation' of a two wire installation is shown. The neutral wire is directly going to the lamp, without intermediate switch.

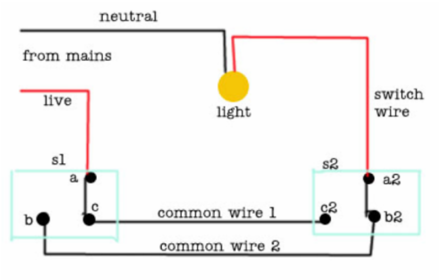


Figure 3-4: Example of a 'two wire installation'

- 'Three wire installation' that contains both the neutral and phase wire between the switch and the lamp. The main advantage is that a power supply for the control switch can easily be obtained but it requires more copper wire for installation.
- A single wire topology with a relays either at the lamp or at a central distribution board.

In most European countries socket-outlets are interconnected with a single line, in the UK a ring circuit topology is used.

Conclusion:
The following topologies will be assumed as typical:
- For lighting in the industry and service sector: a DALI bus cable network topology;
- For socket-outlet: a single line topology;
- For dedicated loads: a point to point connection.

3.1.4.5 Circuit length

Length of circuit stands for the cable distance between distribution board (start point of the circuit) and final terminal point of a circuit. However, the total amount of cable used in the circuit can be larger than the length of the circuit and depends on the topology and the type of circuit. To compensate for the extra cable used in branches, a correction factor is used.

Proposed is to use the following values for the topology influence on the length of circuit:

Table 3-4: Circuit cable length correction factor

Circuit application type	Correction factor
Distribution circuit	1
Lighting circuit	1,2
Socket-outlet circuit	1
Dedicated circuit	1

The empirical values are based upon the fact that most dedicated circuits serve only one appliance, and that for socket-outlet circuits mostly a single line topology is used with zero-length branches. Lighting circuits, however, have branches.

The total length of cable used in the circuit is the length of the circuit multiplied by the correction factor.

The average length in meters of a circuit, based upon the responses on the questionnaire for installers[4], per circuit type and sector is shown in Table 3-5.

Table 3-5: Average circuit length in meters according questionnaire[4]

Sector	Circuit application type	Average length min (m)	Average length ref (m)	Average length max(m)
Residential	Distribution circuit			
	Lighting circuit	10	17,6	30
	Socket-outlet circuit	5	20	50
	Dedicated circuit	5	17	40
Services	Distribution circuit			
	Lighting circuit	12	31,4	60
	Socket-outlet circuit	10	31	65
	Dedicated circuit	10	34	80
Industry	Distribution circuit			
	Lighting circuit	20	54,2	100
	Socket-outlet circuit	15	47,5	100
	Dedicated circuit	15	71,7	200

Conclusion:
Table 3-6 shows the corrected values based upon the values in Table 3-5 multiplied by the correction factor. No values for lengths of distribution circuits were collected, so it is assumed that distribution and dedicated circuits have similar lengths. The proposal is to use the average length values listed in Table 3-6 for the calculation of losses in circuits.

[4] 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 3-6: Corrected (and rounded) average circuit length in meters

Sector	**Circuit application type**	**Average length min (m)**	**Average length ref (m)**	**Average length max(m)**
Residential	Distribution circuit	5	17	40
	Lighting circuit	12	21	3
	Socket-outlet circuit	5	20	50
	Dedicated circuit	5	17	40
Services	Distribution circuit	10	34	80
	Lighting circuit	14	38	72
	Socket-outlet circuit	10	31	65
	Dedicated circuit	10	34	80
Industry	Distribution circuit	15	72	200
	Lighting circuit	24	65	120
	Socket-outlet circuit	15	48	100
	Dedicated circuit	15	72	200

3.1.4.6 Effect of load distribution

In the case of socket-outlets electrical wires are 'branched' to distributed loads and hence losses are not equal within all cable segments. Figure 3-5 shows a typical wiring diagram with branches, the cable loading at the end points or sockets is of course lower compared to the central feeder connection.

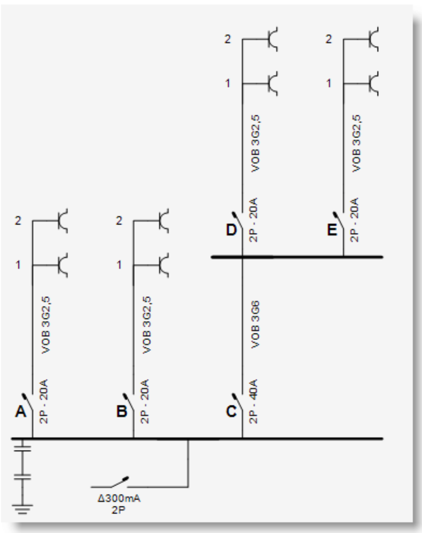


Figure 3-5: Typical wiring diagram

As explained in task 1 the Kd 'distribution factor' is introduced to compensate the distribution of the loading over the cable of a circuit. A 'distribution factor' of 1 means that all cable segments are loaded with the same load current. The Kd 'distribution factor' is lower than or equal to 1.

Table 3-7: Kd factors for circuits with minimum 1 to maximum 8 socket-outlets with equally distributed loads and cable segment lengths

	Number of socket-outlet							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Kd	1	0,61	0,50	0,45	0,42	0,40	0,39	0,38

Table 3-7 shows the calculated Kd factor for circuits with up to 8 socket outlets, equally distributed loads and cable segment lengths. The calculation can be found in annex 3-B.

Table 3-8: Average number of nodes per circuit application type according to questionnaire[5]

Sector	**Circuit application type**	**Average number min (m)**	**Average number ref (m)**	**Average number max(m)**
Residential	Distribution circuit			
	Lighting circuit	5	10.7	30
	Socket-outlet circuit	8	10.3	20
	Dedicated circuit	1	2	3
Services	Distribution circuit			
	Lighting circuit	6	13.8	25
	Socket-outlet circuit	5	6.6	8
	Dedicated circuit	1	2.2	5
Industry	Distribution circuit			
	Lighting circuit	4	14.6	28
	Socket-outlet circuit	2	5.7	18
	Dedicated circuit	1	1.9	5

Conclusion:
Table 3-9 summarises the proposal for average values to be used in this study.

[5] 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 3-9: Kd factor per circuit type

Sector	Circuit application type	Kd min	Kd avg	Kd max
Residential	Distribution circuit		1	
	Lighting circuit	0.38	0.5	1
	Socket-outlet circuit	0.38	0.5	0.9
	Dedicated circuit		1	
Services	Distribution circuit		1	
	Lighting circuit	0.38	0.5	1
	Socket-outlet circuit	0.38	0.5	0.9
	Dedicated circuit		1	
Industry	Distribution circuit		1	
	Lighting circuit	0.38	0.5	1
	Socket-outlet circuit	0.38	0.5	0.9
	Dedicated circuit		1	

3.1.4.7 Effect of not simultaneous functioning of distributed loads

Socket-outlets are connected to multiple loads and when they are not functioning simultaneously this will decrease load current in the circuit. Because losses are proportional to square of the loading current, the losses will be lower. This can be modelled by the so-called 'Rated Diversity Factor'. However, when considering all the loads served by one circuit as one aggregated load, this factor isn't necessary. The diversity factor effect is then incorporated in the load factor and load form factor of the 'circuit load'.

Conclusion:
By using load factor and load form factors associated with a 'circuit load', this factor can be omitted.

3.1.4.8 Ambient temperature

Conductor losses are temperature dependent and therefore higher ambient temperatures have a negative effect on the losses and the current-carrying capacity of the cable. For instance, according IEC 60364-5-52 a correction factor of 0.87 has to applied for PVC cables installed in locations with a ambient temperature of 40°C.

Conclusion:
An ambient temperature of 20°C will be assumed, because this is the normal indoor temperature.

3.1.4.9 Temperature effect caused by the 'method of installation'

Conductor losses are temperature dependent and therefore also the so-called method of installation influences the losses and hence the current-carrying capacity of the cable. This effect is included in standard IEC 60364-5-52 which defines correction factors according to the installation method. IEC 60364-5-52 describes 73 reference installation methods. For each method different correction factors are defined to calculate the current carrying capacity. Figure 3-6 shows some examples of methods of installation and Figure 3-7 the most typical thermal conditions.

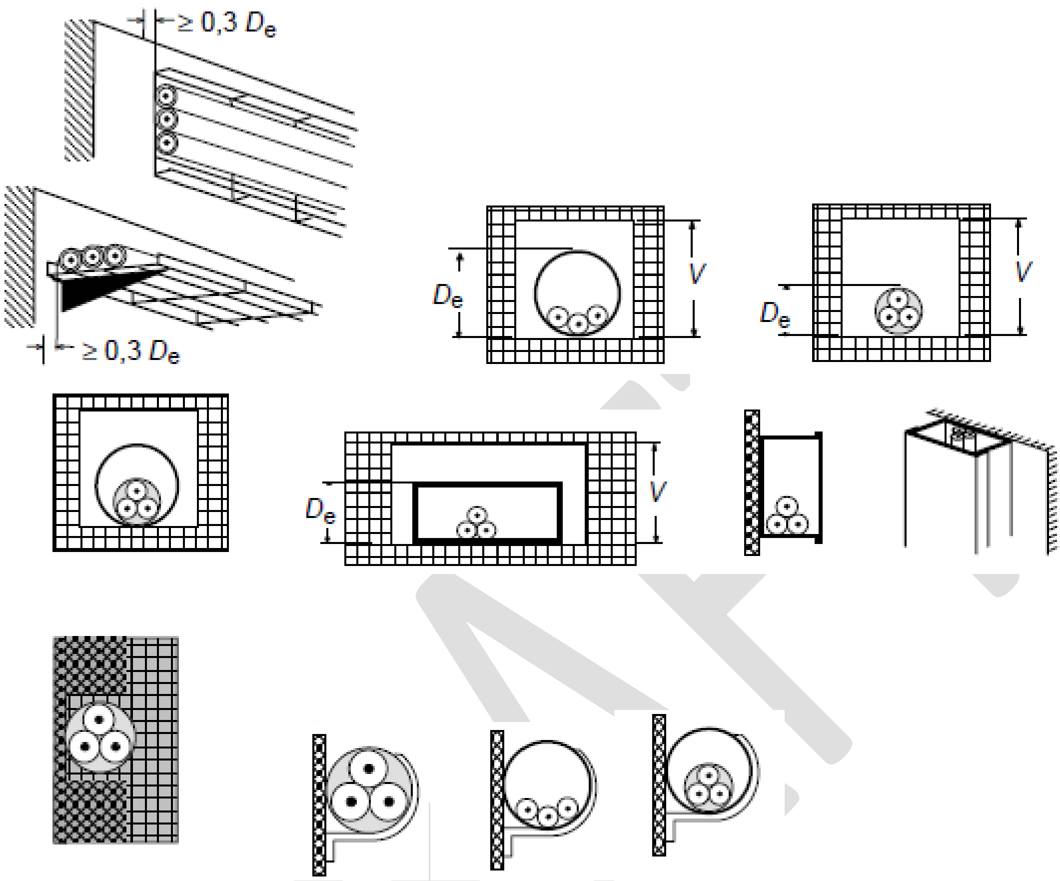


Figure 3-6: Some examples of method of installation (IEC 60364-5-52)

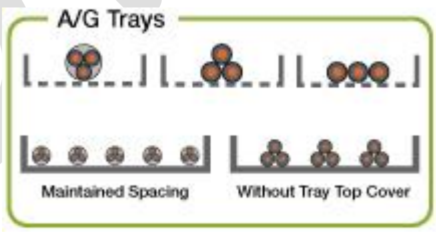


Figure 3-7: Different thermal conditions

Conclusion:
The correction factors in IEC 60364-5-52 related to the method of installation have an impact on the selection of the cross section of a cable. When calculating the losses in a circuit, the cross section is incorporated in the resistance factor of the cable (see formula 3.2 and 3.5).

3.1.4.10 Single or three phase system

See also 3.1.4.1. Of course, in order to have a three phase load connection an three phase grid connection is required.

Conclusion:
See 3.1.4.1.

3.1.4.11 Number of distribution levels

An electrical installation has one or more distribution levels (see definition in Task 1). Small installation have just one level. Larger installations in general have two levels. Exceptionally, very large installations or installations with special design requirements may have a third level.

Conclusion:
No statistics on distribution levels is available. Therefore, two levels will regarded as a reference design in the industry and service sector.

3.1.4.12 Rated Diversity Factor DF at installation level

The Diversity Factor according IEC 61439-3 recognizes that multiple functional units (in this case outgoing circuits at a distribution board or assembly) are in practice not fully loaded simultaneously or are intermittently loaded. The Diversity Factor should be used when calculation the total load in an distribution board/assembly and higher level based upon the sum of the loads in the outgoing circuits of the distribution board.

Different Rated Diversity Factor may be stated for groups of outgoing circuits or for all the outgoing circuits of the assembly/distribution board. Within each of these groups, including the complete assembly, the sum of the rated currents multiplied by the Rated Diversity Factor shall be equal to or higher than the assumed loading currents.

IEC 61439-3 states that in case of lack of information relating to the actual load currents, the Manufacturer will select and declare appropriate Rated Diversity Factor values, preferably from the conventional values listed in in Table 3-10.

Table 3-10: Diversity factor in function of the number of circuits according IEC 61439-3

Number of outgoing circuits	Diversity Factor (DF)
2 and 3	0,8
4 and 5	0,7
6 to 9 inclusive	0,6
10 and above	0,5

Conclusion:
Because of missing statistics on circuit topology and loading, the DF factors indicated in Table 3-10 will be used. This factor should be used when the total load is calculated in function of the loading of each outgoing circuit at the specific distribution level.

3.1.5 Parameters related to the building and loading

Losses in cables depend on the current loading, the relevant loading parameters are explained hereafter.

3.1.5.1 Load Factor (α_c) and load form factor (Kf)

This section describes the used Load factors (α_c =Pavg/S) and Load Form factors (Kf = Prms/Pavg) as defined in chapter 1. To simplify the calculation the loads served by a circuit is regarded as one single virtual load at the end of the circuit (this the reason why α_c and not α is used; α_c stands for corrected or circuit load factor). The Kd distribution factor will compensate this change in topology. The diversity of the different single loads is incorporated into the virtual load.

The load factor α_c is in between 0 and 1. The Load Form factor is always larger than or equal to 1. The product of the load factor and the load form factor is always less than or equal to 1.

Clearly in real conditions current loading (I) (and temperature) have an important influence. In order to calculate the annual energy loss of cables from data files with an estimation of the current loading, it is convenient to switch to time independent parameters and use the so-called RMS load (Prms) or root-mean-square value of the power load load profile. The RMS load values can be computed from data files, e.g. from the Synthetic Load Profiles. The study will investigate which load form factors are most common and could be used in later tasks for assessment of base cases.

When calculating the losses in a circuit, the load profiles for each load of the circuit have to be known. These statistics are however not available. Synthetic Load Profiles are aggregated averaged load profiles of building units (households), and can differ largely from the load profile of a single circuit, and can therefore not be used.

Therefore some general assumptions are made in the calculation of the load and form factors. For instance office lighting[6] have typical annual operating hours ranging from 2000-2500 hours per year which should be equivalent to a load factor (Pavg/S) = 2250h/8760h = 26 %. Assuming the lights are all switched on 2250h a year, and all are switched off the rest of the year results in a Kf equal to 1.96.

Table 3-11, Table 3-12 and Table 3-13 show the calculation of the load factors and load form factors and the assumptions made for this calculation. The calculation is performed per circuit type and per sector. For each of these combinations a low, a reference and a high value is provided.
There are two periods in this model: P1 period 1 and P2 period 2. The sum of the 2 periods is 168, which can be seen as 168 hours in one week. There are two load levels represented by P1 and P2. The ratio between the P2 and P1 load level is given by the P2/P1 ratio. In this model P1 was always 100 (high loading), and P2 (low loading) was always lower than P1. The absolute load values in this calculation have no influence on the calculation.

[6] Preparatory Studies for Eco-design Requirements of EuPs: 'Final report lot 8 on office lighting' (see www.eup4light.net)

To calculate the load factor based upon periods, an additional use factor is introduced. The load factor is calculated as follows:

$$\alpha_c = \frac{period\ 1 + P2/P1\ x\ period\ 2}{period\ 1 + period\ 2}\ x\ use\ factor$$

The use factor indicates the ratio of the design load and the rated maximum load (current-carrying capacity) of the circuit. For instance when assuming 0.3 for a lighting circuit (circuit breaker 10 A, 230 Vac, i.e S= 2300 W) it means that the design load of the circuit is about 690 W.

The terms P2 period 2, Prms, Pavg, Kf, α_c and Kf.α_c are calculated. The other terms are input values and represent the assumptions.

Table 3-11: Load form factor and load factors in the residential sector

	Residential											
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.2	0.3	0.4	0.1	0.2	0.3	0.3	0.4	0.5	0.05	0.1	0.3
P2/P1 ratio	1%	5%	10%	1%	10%	20%	1%	1%	1%	20%	30%	40%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	14	21	28	5	15	25	4	7	14	70	80	90
P2 period 2	1	5	10	1	10	20	1	1	1	20	30	40
Period 2	154	147	140	163	153	143	164	161	154	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	29	36	42	17	31	43	15	20	29	66	72	78
Pavg	9	17	25	4	18	32	3	5	9	53	63	72
Kf	3.12	2.11	1.67	4.38	1.74	1.34	4.61	3.99	3.12	1.24	1.14	1.08
α_c	0.02	0.05	0.10	0.00	0.04	0.10	0.01	0.02	0.05	0.03	0.06	0.22
Kf . α_c	0.06	0.11	0.17	0.02	0.06	0.13	0.05	0.08	0.14	0.03	0.07	0.23

Table 3-12: Load form factor and load factors in the services sector

Services												
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.4	0.5	0.7	0.2	0.3	0.4	0.6	0.7	0.8	0.6	0.7	0.8
P2/P1 ratio	10%	20%	30%	10%	20%	30%	10%	20%	30%	10%	20%	30%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	50	60	70	50	60	70	70	80	90	70	80	90
P2 period 2	10	20	30	10	20	30	10	20	30	10	20	30
Period 2	118	108	98	118	108	98	98	88	78	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	55	62	68	55	62	68	65	71	76	65	71	76
Pavg	37	49	59	37	49	59	48	58	68	48	58	68
Kf	1.50	1.27	1.16	1.50	1.27	1.16	1.37	1.21	1.13	1.37	1.21	1.13
α_c	0.15	0.24	0.41	0.07	0.15	0.24	0.29	0.41	0.54	0.29	0.41	0.54
Kf . α_c	0.22	0.31	0.48	0.11	0.19	0.27	0.39	0.49	0.61	0.39	0.49	0.61

Table 3-13: Load form factor and load factors in the industry sector

	Industry											
	Lighting circuit			**Socket-outlet circuit**			**Dedicated circuit**			**Distribution circuit**		
	Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Use factor	0.4	0.5	0.7	0.2	0.4	0.6	0.6	0.7	0.8	0.6	0.7	0.8
P2/P1 ratio	40%	50%	60%	40%	50%	60%	60%	75%	90%	52%	65%	78%
P1 period 1	100	100	100	100	100	100	100	100	100	100	100	100
Period 1	50	60	70	50	60	70	70	80	90	70	80	90
P2 period 2	40	50	60	40	50	60	60	75	90	52	65	78
Period 2	118	108	98	118	108	98	98	88	78	98	88	78
Period 1 + Period 2	168	168	168	168	168	168	168	168	168	168	168	168
Prms	64	72	79	64	72	79	79	88	95	76	84	90
Pavg	58	68	77	58	68	77	77	87	95	72	82	90
Kf	1.11	1.06	1.03	1.11	1.06	1.03	1.03	1.01	1.00	1.05	1.02	1.01
Lf	0.23	0.34	0.54	0.12	0.27	0.46	0.46	0.61	0.76	0.43	0.57	0.72
Kf . α_c	0.26	0.36	0.55	0.13	0.29	0.47	0.47	0.61	0.76	0.45	0.58	0.72

Conclusion:

Table 3-14 contains the summary of the load factors (α_c) and load form factors (Kf) calculated in Table 3-11, Table 3-12 and Table 3-13.

Table 3-14: Load factors (α_c) and load form factors (Kf) to be used in this study

		Lighting circuit			Socket-outlet circuit			Dedicated circuit			Distribution circuit		
		Low	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**	**Low**	**Ref**	**High**
Residential sector	Kf	3.12	2.11	1.67	4.38	1.74	1.34	4.61	3.99	3.12	1.24	1.14	1.08
	α_c	0.02	0.05	0.10	0.00	0.04	0.10	0.01	0.02	0.05	0.03	0.06	0.22
	Kf . α_c	0.06	0.11	0.17	0.02	0.06	0.13	0.05	0.08	0.14	0.03	0.07	0.23
Services sector	Kf	1.50	1.27	1.16	1.50	1.27	1.16	1.37	1.21	1.13	1.37	1.21	1.13
	α_c	0.15	0.24	0.41	0.07	0.15	0.24	0.29	0.41	0.54	0.29	0.41	0.54
	Kf . α_c	0.22	0.31	0.48	0.11	0.19	0.27	0.39	0.49	0.61	0.39	0.49	0.61
Industry sector	Kf	1.11	1.06	1.03	1.11	1.06	1.03	1.03	1.01	1.00	1.05	1.02	1.01
	α_c	0.23	0.34	0.54	0.12	0.27	0.46	0.46	0.61	0.76	0.46	0.61	0.76
	Kf . α_c	0.26	0.36	0.55	0.13	0.29	0.47	0.47	0.61	0.76	0.47	0.61	0.76

3.1.5.2 Power factor

The power factor is the real power used by the load divided by the apparent power required by the load conditions, see definition in Task 1.

Conclusion:
Although the power factor will differ from circuit to circuit depending on the load type, it is proposed to use PF = 0.9 when load profiles are used.
Rationale: By lack of more precise data the data of the Lot 2 Study on Distribution and Power Transformers will be used.

3.1.5.3 Impact of harmonics

Current harmonics can cause extra losses due to the skin effect and uneven harmonics can cause overload current in the neutral wire[7]. Current losses depend on the type of load[8].

Conclusion:
It is proposed to neglect these losses in further tasks.
Rationale: These losses are neglected because losses are already modelled by the

[7] Leonardo Energy Power Quality Initiative (2001), 'APPLICATION NOTE HARMONICS: CAUSES AND EFFECTS'
[8] Leonardo Energy Power Quality Initiative (2001), 'APPLICATION NOTE HARMONICS: CAUSES AND EFFECTS'

fundamental load current (50 Hz) and more precise data on typical harmonic current of loads is missing.

3.1.5.4 Number of loaded conductors and impact of phase imbalance and harmonics

The number of loaded conductors in a single phase circuit is 2, i.e. the phase conductor and neutral conductor.

IEC 60364-5-52 article 523.6.1 states: " The number of conductors to be considered in a circuit are those carrying load current. Where it can be assumed that conductors in polyphase circuits carry balanced currents, the associated neutral conductor need not be taken into consideration. Under these conditions, a four-core cable is given the same current-carrying capacity as a three-core cable having the same conductor cross-sectional area for each line conductor. Four- and five-core cables may have higher current-carrying capacities when only three conductors are loaded.
This assumption is not valid in the case of the presence of third harmonic or multiples of 3 presenting a THDi (total harmonic distortion) greater than 15%.".

IEC 60364-5-52 article 523.6.2 states: "Where the neutral conductor in a multicore cable carries current as a result of an imbalance in the line currents, the temperature rise due to the neutral current is offset by the reduction in the heat generated by one or more of the line conductors. In this case, the neutral conductor size shall be chosen on the basis of the highest line current.".

IEC 60364-5-52 Annex E states: "Where the neutral current is expected to be higher than the line current then the cable size should be selected on the basis of the neutral current. If the neutral current is more than 135 % of the line current and the cable size is selected on the basis of the neutral current, then the three line conductors will not be fully loaded.".

Table 3-15 shows the reduction factors that should be applied to the design load to calculate the conductor section. For instance, consider a three-phase circuit with a design load of 39 A to be installed using four-core PVC insulated cable clipped to a wall, installation method C. A 6 mm² cable with copper conductors has a current-carrying capacity of 41 A and hence is suitable if harmonics are not present in the circuit. If 20 % third harmonic is present, then a reduction factor of 0,86 is applied and the design load becomes:39/086 = 45 A. As a result a 10 mm² cable is necessary.

Table 3-15: Reduction factors for harmonic currents in four-core and five-core cables[9]

Third harmonic content of line current %	Reduction factor	
	Size selection is based on line current	Size selection is based on neutral current
0 – 15	1,0	–
15 – 33	0,86	–
33 – 45	–	0,86
> 45	–	1,0

[9] IEC 60364-5-52

Conclusion:
The number of loaded conductors in a **single phase** circuit is **2**.

By lack of statistics on the imbalance in the line currents and the THDi in electric circuits, it is proposed to use a balanced system with a THdi of less than 15 % in this study. Consequently, the number of loaded cores in a 3-phase circuit is **3.**

3.1.6 Formulas used for power losses in cables

The general formulas for power losses and energy losses are the following:

- Power losses (in a cable) (Watt): the power losses at a certain moment of time t can be calculated by the following formula:

$$P(t) = R.I^2(t) \text{ (Watt)} \quad \text{(formula 3.1)}$$

- The resistance of a cable at temperature t can be calculated by the following formula:

$$R_t = \rho_t.l/A \ (\Omega) \qquad \text{(formula 3.2)}$$

  where,
  - ρ_t= specific electrical resistance of the conductor at temperature t (Ω.mm²/m)[10]
  - l= length of the cable (meter)
  - A= cross sectional area of the conductor (mm²)

- Energy losses(E) according to the laws of physics:

$$E = \int_0^T R.I^2(t) \qquad \text{(formula 3.3)}$$

- Energy loss in cables according to IEC 60287-3-2:

$$energy\ loss\ during\ the\ first\ year = I^2max.\ RL.L.NP.NC.T \qquad \text{(formula 3.4)}$$

  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.

  Note: the formula used in IEC 60287-3-2 is only applicable to calculate the cable losses in a 'single cable segments' of a circuit.

- The formula in this study to calculate the annual energy loss (E (loss)) in a circuit cable based upon the above mentioned factors is:

[10] ρ_t is the resistivity of conductors 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 Ωmm²/m for copper and 0,036 Ωmm²/m for aluminium; IEC 60364-5-52 annex G

$$E_{circuit}(y)\ [kWh] = Kd \times R_t \times Imax^2 \times (\alpha_c \times Kf/PF)^2 \times 8760 / 1000$$

(formula 3.5)

where,

- Kd = the distribution factor
- R_t = cable resistance at temperature t (see formula 3.2)
- Imax = the maximum rated current of the cable
- α_c = The corrected load factor
- Kf = Load form factor (=Prms/Pavg)
- PF = the power factor of the load served by the power cable.

Note: Prms requires the calculation of an integral of the load profile and therefore aligns with formula 3.3.

3.2 Systems aspects of the use phase for ErPs with indirect impact

The following systems are impacted in the use phase by the ErP.

3.2.1 Building space heating and cooling system

Cable losses are dissipated in the form of heat energy and therefore contribute to so-called 'internal heat gains', this has and impact on the building heating and cooling requirements. The impact can be positive when heating is needed or negative when cooling is needed.

Conclusion: because the impact can be positive or negative and it is not the primary function of the cable to contribute to the heating it is proposed to further neglect this effect in the study.

3.3 End-of-Life behaviour

General description of end-of-life process:

Copper is a valuable material and therefore cables are in general returned for recycling. In 2009 recycled copper met 45,7% of Europe's copper demand[11]. In this process PVC insulation is separated mechanically from copper with shredders and granulators. The main purpose is to recover the valuable copper but when transport cost are economically viable PVC insulation is also sold for recycling. Recycling of PVC is done with Vinyloop technology[12]. The main purpose is to recycle PVC from cable insulation and other scrap materials. The technology was developed by Solvay's R&D centre in Brussels and awarded patent rights in 1998. The process uses the total solubility of PVC in solvents to separate the PVC from other components in the scrap.
Note: This study deals with new power cables entering the market and that will have to be recycled when buildings are renovated (>20 years).

[11] http://eurocopper.org/copper/copper-information.html
[12] http://www.chemicals-technology.com/projects/ferrara/

Assumptions made in this study (Stakeholders please provide input):

- Present fractions to recycling, re-use and disposal for copper: 95%?, 0%, 5%?
- Present fractions to recycling, re-use and disposal for aluminium: 95%?, 0%, 5%?
- Present fractions to recycling, re-use and disposal for insulation: 50%?, 0%, 50%?
- Present fraction of second hand use and refurbishment: 0%
- Product use & stock life: 40 years?
- Repair & maintenance practice: not existing
- Collection rate: 95 %?
- Second hand use: not existing

Available good practice in product use

3.4 Local infrastructure (barriers and opportunities)

3.4.1 Opportunities

3.4.1.1 Effect on electrical installation and end-user

Reliability, availability and nature of the energy will not change when the resistance of the electrical system is changed.
increasing the wiring size will also not influence the users of the buildings because the cables are typically hidden in walls or behind panels. Probably the users do not at all notice whether the wirings are slightly thicker or thinner.

3.4.1.2 Certification

Certification of the electric installation in buildings is in most of the EU countries required by legislation. Measures at the level of the electrical installation could therefore be verified and enforced at the certification stage. For instance in Belgium the electrical installations in houses need to be recertified when a house is sold. In the industrial and services sector in Belgium the local regulation specifies that recertification of the electrical installation by a certification authority has to be performed every 5 years.

Stakeholders can provide more input

3.4.1.3 Refurbishment occasions

Refurbishment occasions, like when houses are sold, provide an opportunity to stimulate the renovation of electrical installations.

In the residential sector financial incentive structures are one of the main instruments in redressing householders unwillingness or inability to invest in energy efficiency by themselves. Financial incentives for energy efficiency measures, like wall insulation or new windows, may also stimulate house owners to renew the electrical installation.

3.4.2 Barriers

3.4.2.1 Lock-in effect into existing installations

As illustrated in Figure 3-6 the cable can be placed direct in masonry or wooden wall, in conduits, cable ducts, on cable ladder, on brackets, on trays, in building voids, in a channel in the floor and so on. This installation method can create a kind of lock-in effect. In some of the methods the cables cannot be easily replaced unless a thorough renovation is done, for instance when the cables are placed direct in the masonry, making it more costly.

In the residential sector installers will choose more often methods of installation (lower cost) for which the cables are more difficult to replace. In the industry and services sector it often part of the requirements of the electrical installation that the cables have to be placed in ducts, conduits or voids, and are therefore easier to be replaced.

3.4.2.2 Implication on material use

Strategies like S+x will result for the same system in a larger use of material for the conductor and the insulation.

The relative increase in conductor material can be calculated with Formula 3.6. As mentioned in Task 1 in Annex B a S+1 strategy will result in additional conductor material use of 20% to 67%. A S+2 strategy will result in additional conductor material use of 50% to 167%. Even when not applied to all sectors and with a penetration rate of 45% (see Task 1 First screening) this would mean an additional use of conductor material of minimum 1,166 and maximum 3,885 million tonnes for the S+1 strategy, and minimum 2,914 and maximum 9,713 million tonnes for the S+2 strategy (see Table 3-16 and Table 3-17).

$$\textit{relative conductor volume increase} = \frac{V_{S+x} - V_S}{V_S} = \frac{r_{S+x}^2 - r_S^2}{r_S^2} \qquad \text{(formula 3.6)}$$

Where:

$V = (r^2)\pi L$
r = radius of conductor section
L = length of the cable
S and S+x indicate the associated CSA strategy

Table 3-16: Relative volume increase based upon S+x strategy

relative volume increase based upon S+x strategy						
		S+1	S+2	S+3	S+4	S+5
100% penetration	Minimum	20%	50%	90%	140%	200%
	Maximum	67%	167%	317%	567%	967%
45% penetration	Minimum	9%	23%	41%	63%	90%
	Maximum	30%	75%	143%	255%	435%

Table 3-17: Conductor material use increase in kTon based upon S+x strategy up to 2030

conductor material use increase in kTon based upon S+x strategy up to 2030						
Stock of power cables in services and industry in 2030 (kTon)	12950					
		S+1	S+2	S+3	S+4	S+5
100% penetration	Minimum	2590	6475	11717	18130	25900
	Maximum	8633	21583	41008	73383	125183
45% penetration	Minimum	1166	2914	5273	8159	11655
	Maximum	3885	9713	18454	33023	56333

The additional amount of material may have following consequences:

- Additional material use means additional mining and treatment of the raw material, with extra CO_2 emission;
- A slight increase in material price. In 2007 global copper demand was 24.2 million tonnes, of which 48% was used in the manufacture of electric cable[13]. In 2009 recycled copper met 45,7% of Europe's demand[14]. So an increase of about 1,2 to 9,7 million tons over 15 year (S+1, S+2) means about 0,08 to 0,65 million tonnes extra per year.

Also a strategy like dual wiring would mean significant increase in material use.

Insulation material increase:

The relative increase in insulation material can be calculated with Formula 3.7. Assuming the outer radius increases with the same factor as the inner radius of the insulation cylinder for a s+x strategy, Table 3-19 in annex 3-A shows the increase in insulation volume for a S+x strategy. In this case the relative insulation volume increase is equal to the relative conductor volume increase for a strategy S+x.
In case of a dual wire strategy the used insulation material volume doubles.

$$relative\ insulation\ volume\ increase = \frac{V_{S+x} - V_S}{V_S} \qquad \text{(formula 3.7)}$$

Where:

$V = (r_o^2 - r_i^2)\pi L$
r_o = outer radius of insulation cylinder
r_i = inner radius of insulation cylinder = radius of conductor section
L = length of the cable
S and S+x indicate the associated CSA strategy

Conclusion:
The relative increase of conductor and insulation material for a S+x strategy can be calculated with formula 3.6 respectively formula 3.7. In case of a dual wire strategy the used conductor and insulation material volume doubles (=100% increase).

13 www.eurocopper.org, "Modified Cable Sizing Strategies, Potential Savings" study – Egemin Consulting for European Copper Institute – May 2011
14 http://eurocopper.org/copper/copper-information.html

3.4.2.3 Handling and space requirements

Strategies like dual wiring and S+x strategies requires more space for the wiring in the building. Wires with larger sizes have also larger bending curves and are more difficult to handle.

3.4.2.4 Economic product life (=actual time to disposal)

Lifetime is a crucial component of the life cycle cost (LCC) calculation. Power cables are durable and have long working lives.

The following material[15] (Table 3-18) with lifetime figures for a wide range of products was developed for the US National Association of Home Builders (NAHB) Economics Department based on a survey of manufacturers, trade associations and product researchers.

Table 3-18: Lifetime of wiring according NAHB

Electrical	Life in years
Copper wiring, copper plated, copper clad aluminum, and bare copper	100+
Armored cable (BX)	Lifetime
Conduit	Lifetime

Source: Jesse Aronstein, Engineering Consultant

International Association of Certified Home Inspectors (NACHI)[16] and NAHB charts agree that copper wiring can last 100 years or more. But the real life expectancy of your wiring is not in the copper. It's dependent on the wiring's insulation, and that lifetime can vary widely.

The modern formula for thermoplastic NM-B type wiring dates from 1984, when the insulation's heat resistance was increased. The best guess is that it will provide over 100 years of service.

Therefore, it can be concluded that the economic product lifetime of wiring in modern electrical installations is not determined by the technical lifetime of wiring. Power cables are part of the electrical installation and are in general replaced when the complete electrical installation is renovated. An electrical installation will be partially or completely renewed when the building environment served by the electrical installation is changed or gets a new function. Also when new machinery or appliances are added to the installation it might be necessary to replace or upgrade part of the electrical installation. Therefore it's safe to conclude that the lifetime of electrical wiring is determined by the lifetime of the system of which the wiring is a component, thus the electrical installation.

[15] http://www.oldhouseweb.com/how-to-advice/life-expectancy.shtml

[16] http://www.improvementcenter.com/electrical/home-electrical-system-how-long-can-it-last.html

Conclusion:
The economic product lifetime therefore is determined by the refurbishment rate of the building. This refurbishment rate is related to the function type of the building (see chapter 2).

3.4.3 Installers and certifiers of electrical installations

Potential affected:

- Electrical installation engineering companies
- Installers
- Certifiers

Designing taking energy efficiency and economy into account might require installers to invest in extra training, and design tools. These design tools have to be adapted by software development companies.

Installation time and related cost may increase due to extra wiring or more difficult handling of cables with larger sizes.

Installing extra cables or cables with a larger size will have no implications on the required know-how of the installer. Installers in the non-residential sector are used to handle large cable sizes.

Depending on the policy certifiers may have to include extra procedures in the certification process to verify the electrical installation.

3.4.4 Physical environment

As discussed in Task 1 the losses in electrical installations can be reduced by increasing the cable section or by reducing the load per circuit, having additional circuits for the same amount of load.

The building construction and electric installation will be affected by:

- thicker cables are less flexible and need more volume/space for installation
- the connectors for thicker cables may be different and larger
- having more circuits will increase the space requirements for the distribution boards
- having more circuits will increase the space requirements the cables (ducts)

3.5 Recommendations

TBC

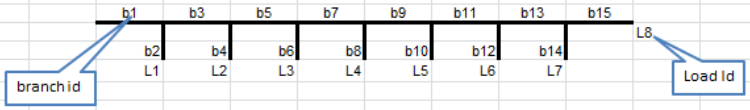
ANNEX A

Table 3-19: Insulation increase

CSA (S)	Radius	radius increase					insulation volume increase				
mm²	mm	S+1	S+2	S+3	S+4	S+5	S+1	S+2	S+3	S+4	S+5
0,5	0,40	22%	41%	73%	124%	183%	50%	100%	200%	400%	700%
0,75	0,49	15%	41%	83%	131%	183%	33%	100%	233%	433%	700%
1	0,56	22%	58%	100%	145%	216%	50%	150%	300%	500%	900%
1,5	0,69	29%	63%	100%	158%	227%	67%	167%	300%	567%	967%
2,5	0,89	26%	55%	100%	153%	216%	60%	140%	300%	540%	900%
4	1,13	22%	58%	100%	150%	196%	50%	150%	300%	525%	775%
6	1,38	29%	63%	104%	142%	189%	67%	167%	317%	483%	733%
10	1,78	26%	58%	87%	124%	165%	60%	150%	250%	400%	600%
16	2,26	25%	48%	77%	109%	144%	56%	119%	213%	338%	494%
25	2,82	18%	41%	67%	95%	119%	40%	100%	180%	280%	380%
35	3,34	20%	41%	65%	85%	107%	43%	100%	171%	243%	329%
50	3,99	18%	38%	55%	73%	92%	40%	90%	140%	200%	270%
70	4,72	16%	31%	46%	63%	85%	36%	71%	114%	164%	243%
95	5,50	12%	26%	40%	59%	78%	26%	58%	95%	153%	216%
120	6,18	12%	24%	41%	58%	83%	25%	54%	100%	150%	233%
150	6,91	11%	26%	41%	63%	83%	23%	60%	100%	167%	233%
185	7,67	14%	27%	47%	64%	85%	30%	62%	116%	170%	241%
240	8,74	12%	29%	44%	62%	83%	25%	67%	108%	163%	233%
300	9,77	15%	29%	45%	63%	83%	33%	67%	110%	167%	233%
400	11,28	12%	25%	41%	58%	73%	25%	58%	100%	150%	200%
500	12,62	12%	26%	41%	55%		26%	60%	100%	140%	
630	14,16	13%	26%	38%			27%	59%	90%		
800	15,96	12%	22%				25%	50%			
1000	17,84	10%					20%				
1200	19,54										
Minimum		10%	22%	38%	55%	73%	20%	50%	90%	140%	200%
Maximum		29%	63%	104%	158%	227%	67%	167%	317%	567%	967%
Average		18%	39%	65%	96%	132%	39%	95%	178%	297%	467%
Average for CSA 1,5 till CSA 6		27%	60%	101%	151%	207%	61%	156%	304%	529%	844%
Average for CSA 1,5 till CSA 25		25%	55%	91%	133%	179%	57%	142%	266%	448%	693%
Average for CSA 10 till CSA 70		21%	43%	66%	91%	119%	46%	105%	178%	271%	386%

Annex B

CSA circuit	2,5	mm^2
Cable resistivity per m	0,00672	Ω/m
Number of relevant cores	2	
I_{max} (circuit breaker)	16	A
Voltage	230	V
Pmax	3680	W
Circuit (total cable) length	30	m
Circuit loss at Imax	103,2192	W
Load branch length factor	10%	%



Number of branches with loa	1		2		3		4		5		6		7		8	
Load Id	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current	Power usage	Current
	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A
1	3680	16	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
2	0	0	1840	8	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
3	0	0	0	0	1226,67	5,33333	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
4	0	0	0	0	0	0	920	4	736	3,2	613,333	2,66667	525,714	2,28571	460	2
5	0	0	0	0	0	0	0	0	736	3,2	613,333	2,66667	525,714	2,28571	460	2
6	0	0	0	0	0	0	0	0	0	0	613,333	2,66667	525,714	2,28571	460	2
7	0	0	0	0	0	0	0	0	0	0	0	0	525,714	2,28571	460	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	2

Branch id	1 Current	1 Length	1 loss (R.I²)	2 Current	2 Length	2 loss (R.I²)	3 Current	3 Length	3 loss (R.I²)	4 Current	4 Length	4 loss (R.I²)
	A	m	W	A	m	W	A	m	W	A	m	W
1	16,00	30,00	103,22	16,00	14,50	49,89	16,00	9,60	33,03	16,00	7,18	24,70
2	0,00	0,00	0,00	8,00	1,00	0,86	5,33	0,60	0,23	4,00	0,43	0,09
3	0,00	0,00	0,00	8,00	14,50	12,47	10,67	9,60	14,68	12,00	7,18	13,89
4	0,00	0,00	0,00	0,00	0,00	0,00	5,33	0,60	0,23	4,00	0,43	0,09
5	0,00	0,00	0,00	0,00	0,00	0,00	5,33	9,60	3,67	8,00	7,18	6,17
6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	0,43	0,09
7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	7,18	1,54
8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total		30,00	103,22		30,00	63,22		30,00	51,84		30,00	46,59
Kd			1,00			0,61			0,50			0,45

Branch id	5 Current	5 Length	5 loss (R.I²)	6 Current	6 Length	6 loss (R.I²)	7 Current	7 Length	7 loss (R.I²)	8 Current	8 Length	8 loss (R.I²)
	A	m	W	A	m	W	A	m	W	A	m	W
1	16,00	5,73	19,73	16,00	4,77	16,42	16,00	4,09	14,07	16,00	3,58	12,30
2	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
3	12,80	5,73	12,62	13,33	4,77	11,40	13,71	4,09	10,33	14,00	3,58	9,42
4	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
5	9,60	5,73	7,10	10,67	4,77	7,30	11,43	4,09	7,18	12,00	3,58	6,92
6	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
7	6,40	5,73	3,16	8,00	4,77	4,11	9,14	4,09	4,59	10,00	3,58	4,80
8	3,20	0,33	0,05	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
9	3,20	5,73	0,79	5,33	4,77	1,82	6,86	4,09	2,58	8,00	3,58	3,08
10	0,00	0,00	0,00	2,67	0,27	0,03	2,29	0,23	0,02	2,00	0,20	0,01
11	0,00	0,00	0,00	2,67	4,77	0,46	4,57	4,09	1,15	6,00	3,58	1,73
12	0,00	0,00	0,00	0,00	0,00	0,00	2,29	0,23	0,02	2,00	0,20	0,01
13	0,00	0,00	0,00	0,00	0,00	0,00	2,29	4,09	0,29	4,00	3,58	0,77
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,20	0,01
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	3,58	0,19
Total		30,00	43,58		30,00	41,64		30,00	40,28		30,00	39,28
Kd			0,42			0,40			0,39			0,38