BS IEC 60287-2-1:2015

BSI Standards Publication

Electric cables — Calculation of the current rating

Part 2-1: Thermal resistance — Calculation of thermal resistance

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National foreword

This British Standard is the UK implementation of IEC 60287-2-1:2015. It supersedes BS IEC 60287-2-1:1994+A2:2006 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/20, Electric cables, to Subcommittee GEL/20/16, Electric Cables - Medium/high voltage.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Part 2-1: Thermal resistance – Calculation of thermal resistance

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Partie 2-1: Résistance thermique – Calcul de la résistance thermique

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 2-1: Thermal resistance – Calculation of thermal resistance

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60287-2-1 has been prepared by IEC technical committee 20: Electric cables.

This second edition of IEC 60287-2-1 cancels and replaces the first edition, published in 1994, Amendment 1:2001, Amendment 2:2006 and Corrigendum 1:2008. The document 20/1448/CDV, circulated to the National Committees as Amendment 3, led to the publication of this new edition. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) inclusion of a reference to the use of finite element methods where analytical methods are not available for the calculation of external thermal resistance;
b) explanation about SL and SA type cables;

c) calculation method for T3 for unarmoured three-core cables with extruded insulation and individual copper tape screens on each core;

d) change of condition for X in 5.4;

e) inclusion of constants or installation conditions for water filled ducts in Table 4.

The text of this standard is based on the following documents:

FDIS	Report on voting
20/1561/FDIS	20/1588/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60287 series, published under the general title *Electric cables – Calculation of the current rating*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

IEC 60287 has been divided into three parts so that revisions of, and additions to the document can be carried out more conveniently.

Each part is subdivided into subparts which are published as separate standards.

Part 1: Formulae of ratings and power losses

Part 2: Formulae for thermal resistance

Part 3: Operating conditions

This part of IEC 60287-2 contains methods for calculating the internal thermal resistance of cables and the external thermal resistance for cables laid in free air, ducts and buried.

The formulae in this standard contain quantities which vary with cable design and materials used. The values given in the tables are either internationally agreed, for example, electrical resistivities and resistance temperature coefficients, or are those which are generally accepted in practice, for example, thermal resistivities and permittivities of materials. In this latter category, some of the values given are not characteristic of the quality of new cables but are considered to apply to cables after a long period of use. In order that uniform and comparable results may be obtained, the current ratings should be calculated with the values given in this standard. However, where it is known with certainty that other values are more appropriate to the materials and design, then these may be used, and the corresponding current rating declared in addition, provided that the different values are quoted.

Quantities related to the operating conditions of cables are liable to vary considerably from one country to another. For instance, with respect to the ambient temperature and soil thermal resistivity, the values are governed in various countries by different considerations. Superficial comparisons between the values used in the various countries may lead to erroneous conclusions if they are not based on common criteria: for example, there may be different expectations for the life of the cables, and in some countries design is based on maximum values of soil thermal resistivity, whereas in others average values are used. Particularly, in the case of soil thermal resistivity, it is well known that this quantity is very sensitive to soil moisture content and may vary significantly with time, depending on the soil type, the topographical and meteorological conditions, and the cable loading.

The following procedure for choosing the values for the various parameters should, therefore, be adopted:

Numerical values should preferably be based on results of suitable measurements. Often such results are already included in national specifications as recommended values, so that the calculation may be based on these values generally used in the country in question; a survey of such values is given in IEC 60287-3-1.

A suggested list of the information required to select the appropriate type of cable is given in IEC 60287-3-1.

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 2-1: Thermal resistance – Calculation of thermal resistance

1 Scope

This part of IEC 60287 is solely 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, in 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.

This part of IEC 60287 provides formulae for thermal resistance.

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).

Equations given in this part of IEC 60287 for calculating the external thermal resistance of a cable buried directly in the ground or in a buried duct are for a limited number of installation conditions. Where analytical methods are not available for calculation of external thermal resistance finite element methods may be used. Guidance on the use of finite element methods for calculating cable current ratings is given in IEC TR 62095.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60287-1-1:2006, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*
IEC 60287-1-1:2006/AMD1:2014

IEC 60853-2, *Calculation of the cyclic and emergency current rating of cables – Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages*

3 Symbols

The symbols used in this part of IEC 60287 and the quantities which they represent are given in the following list:

D'_a	external diameter of armour	mm
D_d	internal diameter of duct	mm
D_e	external diameter of cable, or equivalent diameter of a group of cores in pipe-type cable	mm
D_e^*	external diameter of cable (used in 4.2.1)	m
D_o	external diameter of duct	mm
D_s	external diameter of metal sheath	mm
D_{oc}	the diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath	mm
D_{ot}	the diameter of the imaginary coaxial cylinder which would just touch the outside surface of the troughs of a corrugated sheath = $D_{it} + 2t_s$	mm
D_{ic}	the diameter of the imaginary cylinder which would just touch the inside surface of the crests of a corrugated sheath = $D_{oc} - 2t_s$	mm
D_{it}	the diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath	mm
E	constant used in 4.2.1.1	
F_1	coefficient for belted cables defined in 4.1.2.2.3	
F_2	coefficient for belted cables defined in 4.1.2.2.6	
G	geometric factor for belted cables	
$\overline{G}$	geometric factor for SL and SA type cables	
H	intensity of solar radiation (see 4.2.1.2)	W/m^2
K	screening factor for the thermal resistance of screened cables	
K_A	coefficient used in 4.2.1	
L	depth of laying, to cable axis or centre of trefoil	mm
L_G	distance from the soil surface to the centre of a duct bank	mm
N	number of loaded cables in a duct bank (see 4.2.7.4)	
T_1	thermal resistance per core between conductor and sheath	K·m/W
T_2	thermal resistance between sheath and armour	K·m/W
T_3	thermal resistance of external serving	K·m/W
T_4	thermal resistance of surrounding medium (ratio of cable surface temperature rise above ambient to the losses per unit length)	K·m/W
T_4^*	external thermal resistance in free air, adjusted for solar radiation	K·m/W
T'_4	thermal resistance between cable and duct (or pipe)	K·m/W
T''_4	thermal resistance of the duct (or pipe)	K·m/W
T'''_4	thermal resistance of the medium surrounding the duct (or pipe)	K·m/W
U	constant used in 4.2.7.2	
V	constant used in 4.2.7.2	
W_d	dielectric losses per unit length per phase	W/m
W_k	losses dissipated by cable k	W/m
W_{TOT}	total power dissipated in the trough per unit length	W/m
Y	coefficient used in 4.2.7.2	
Z	coefficient used in 4.2.1.1	

d_a	external diameter of belt insulation	mm
d_c	external diameter of conductor	mm
d_{cm}	minor diameter of an oval conductor	mm
d_{cM}	major diameter of an oval conductor	mm
d_M	major diameter of screen or sheath of an oval conductor	mm
d_m	minor diameter of screen or sheath of an oval conductor	mm
d_x	diameter of an equivalent circular conductor having the same cross-sectional area and degree of compactness as the shaped one	mm
g	coefficient used in 4.2.1.1	
h	heat dissipation coefficient	$W/m^2K^{5/4}$
ln	natural logarithm (logarithm to base e)	
n	number of conductors in a cable	
p	the part of the perimeter of the cable trough which is effective for heat dissipation (see 4.2.6.2)	m
r_1	circumscribing radius of two or three-sector shaped conductors	mm
s_1	axial separation of two adjacent cables in a horizontal group of three, not touching	mm
t	insulation thickness between conductors	mm
t_1	insulation thickness between conductors and sheath	mm
t_2	thickness of the bedding	mm
t_3	thickness of the serving	mm
t_i	thickness of core insulation, including screening tapes plus half the thickness of any non-metallic tapes over the laid up cores	mm
t_s	thickness of the sheath	mm
u	$\frac{2L}{D_e}$ in 4.2.	
u	$\frac{L_G}{r_b}$ in 4.2.7.4	
x, y	sides of duct bank ($y>x$) (see 4.2.7.4)	mm
θ_m	mean temperature of medium between a cable and duct or pipe	°C
$\Delta\theta$	permissible temperature rise of conductor above ambient temperature	K
$\Delta\theta_d$	factor to account for dielectric loss for calculating T_4 for cables in free air	K
$\Delta\theta_{ds}$	factor to account for both dielectric loss and direct solar radiation for calculating T_4^* for cables in free air using Figure 10	K
$\Delta\theta_{duct}$	difference between the mean temperature of air in a duct and ambient temperature	K
$\Delta\theta_s$	difference between the surface temperature of a cable in air and ambient temperature	K
$\Delta\theta_{tr}$	temperature rise of the air in a cable trough	K
λ_1, λ_2	ratio of the total losses in metallic sheaths and armour respectively to the total conductor losses (or losses in one sheath or armour to the losses in one conductor)	

λ'_{1m}	loss factor for the middle cable	Three cables in flat formation without transposition, with sheaths bonded at both ends
λ'_{11}	loss factor for the outer cable with the greater losses	
λ'_{12}	loss factor for the outer cable with the least losses	

ρ_i	thermal resistivity of the insulation	K·m/W
ρ_f	thermal resistivity of the filler material	K·m/W
ρ_e	thermal resistivity of earth surrounding a duct bank	K·m/W
ρ_c	thermal resistivity of concrete used for a duct bank	K·m/W
ρ_m	thermal resistivity of metallic screens on multicore cables	K·m/W
ρ_T	thermal resistivity of material	K·m/W
σ	absorption coefficient of solar radiation for the cable surface	

4 Calculation of thermal resistances

4.1 Thermal resistance of the constituent parts of a cable, T_1, T_2 and T_3

4.1.1 General

Clause 4 gives the formulae for calculating the thermal resistances per unit length of the different parts of the cable T_1, T_2 and T_3 (see 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014). The thermal resistivities of materials used for insulation and for protective coverings are given in Table 1.

Where screening layers are present, for thermal calculations metallic tapes are considered to be part of the conductor or sheath while semi-conducting layers (including metallized carbon paper tapes) are considered as part of the insulation. The appropriate component dimensions shall be modified accordingly.

4.1.2 Thermal resistance between one conductor and sheath T_1

4.1.2.1 Single-core cables

The thermal resistance between one conductor and the sheath T_1 is given by:

$$T_1 = \frac{\rho_T}{2\pi} \ln\left[1 + \frac{2\,t_1}{d_c}\right]$$

where

ρ_T is the thermal resistivity of insulation (K·m/W);

d_c is the diameter of conductor (mm);

t_1 is the thickness of insulation between conductor and sheath mm).

NOTE For corrugated sheaths, t_1 is based on the mean internal diameter of the sheath which is given by:

$$\left(\frac{D_{it} + D_{oc}}{2}\right) - t_s$$

4.1.2.2 Belted cables

4.1.2.2.1 General

The thermal resistance T_1 between one conductor and sheath is given by:

$$T_1 = \frac{\rho_T}{2\pi} G$$

where

G is the geometric factor

NOTE For corrugated sheaths, t_1 is based on the mean internal diameter of the sheath which is given by:

$$\left(\frac{D_{it} + D_{oc}}{2}\right) - t_s$$

4.1.2.2.2 Two-core belted cables with circular conductors

The geometric factor G is given in Figure 2.

4.1.2.2.3 Two-core belted cables with sector-shaped conductors

The geometric factor G is given by:

$$G = 2\, F_1 \ln\left[\frac{d_a}{2\, r_1}\right]$$

where

$$F_1 = 1 + \frac{2{,}2\, t}{2\pi\,(d_x + t) - t}$$

d_a is the external diameter of the belt insulation (mm);

r_1 is the radius of the circle circumscribing the conductors (mm);

d_x is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

t is the insulation thickness between conductors (mm).

4.1.2.2.4 Three-core belted cables with circular conductors

For three-core belted cables with circular conductors

$$T_1 = \frac{\rho_i}{2\pi} G + 0{,}031\left(\rho_f - \rho_i\right) e^{0{,}67 \frac{t_1}{d_c}}$$

where

ρ_i is the thermal resistivity of the insulation (K·m/W);

ρ_f is the thermal resistivity of the filler material (K·m/W).

The geometric factor G is given in Figure 3.

NOTE For paper-insulated cables $\rho_f = \rho_i$ and, hence, the second term on the right hand side of the above equation can be ignored.

For cables with extruded insulation, the thermal resistivity of the filler material is likely to be between 6 K·m/W and 13 K·m/W, depending on the filler material and its compaction. A value of 10 K·m/W is suggested for fibrous polypropylene fillers.

The above equation is applicable to cables with extruded insulation where each core has an individual screen of spaced wires and to cables with a common metallic screen over all three cores. For unarmoured cables of this design t_1 is taken to be the thickness of the material between the conductors and outer covering (serving).

4.1.2.2.5 Three-core belted cables with oval conductors

The cable shall be treated as an equivalent circular conductor cable with an equivalent diameter $d_c = \sqrt{d_{cM} \times d_{cm}}$ (mm)

where

d_{cM} is the major diameter of the oval conductor (mm);

d_{cm} is the minor diameter of the oval conductor (mm).

4.1.2.2.6 Three-core belted cables with sector-shaped conductors

The geometric factor G for these cables depends on the shape of the sectors, which varies from one manufacturer to another. A suitable formula is:

$$G = 3 F_2 \ln\left[\frac{d_a}{2 r_1}\right]$$

where

$$F_2 = 1 + \frac{3t}{2\pi (d_x + t) - t}$$

d_a is the external diameter of the belt insulation (mm);

r_1 is the radius of the circle circumscribing the conductors (mm);

d_x is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

t is the insulation thickness between conductors (mm).

4.1.2.3 Three-core cables, metal tape screened type

4.1.2.3.1 Screened cables with circular conductors

Paper insulated of this type may be first considered as belted cables for which $\frac{t_1}{t}$ is 0,5. Then, in order to take account of the thermal conductivity of the metallic screens, the result shall be multiplied by a factor K, called the screening factor, which is given in Figure 4 for different values of $\frac{t_1}{d_c}$ and different cable specifications.

Thus:

$$T_1 = K \frac{\rho_T}{2\pi} G$$

Three-core cables with extruded insulation and individual copper tape screens on each core should be treated as SL type cables (see 4.1.2.5 and 4.1.3.2).

See 4.1.2.2.4 for three-core cables with extruded insulation and an individual screen of spaced copper wires on each core or a common metallic screen over all three cores.

4.1.2.3.2 Screened cables with oval-shaped conductors

The cable shall be treated as an equivalent circular conductor cable with an equivalent diameter $d_c = \sqrt{d_{cM} \cdot d_{cm}}$.

4.1.2.3.3 Screened cables with sector-shaped conductors

T_1 is calculated for these cables in the same way as for belted cables with sector-shaped conductors, but d_a is taken as the diameter of a circle which circumscribes the core assembly. The result is multiplied by a screening factor given in Figure 5.

4.1.2.4 Oil-filled cables

4.1.2.4.1 Three-core cables with circular conductors and metallized paper core screens and circular oil ducts between the cores

The thermal resistance between one conductor and the sheath T_1 is given by:

$$T_1 = 0{,}385\,\rho_T \left(\frac{2\,t_i}{d_c + 2\,t_i} \right)$$

where

d_c is the conductor diameter (mm);

t_i is the thickness of core insulation including carbon black and metallized paper tapes plus half of any non-metallic tapes over the three laid up cores (mm);

ρ_T is the thermal resistivity of insulation (K·m/W).

This formula assumes that the space occupied by the metal ducts and the oil inside them has a thermal conductance very high compared with the insulation, it therefore applies irrespective of the metal used to form the duct or its thickness.

4.1.2.4.2 Three-core cables with circular conductors and metal tape core screens and circular oil ducts between the cores

The thermal resistance T_1 between one conductor and the sheath is given by:

$$T_1 = 0{,}35\,\rho_T \left(0{,}923 - \frac{d_c}{d_c + 2\,t_i} \right)$$

where

t_i is the thickness of core insulation including the metal screening tapes and half on any non-metallic tapes over the three laid up cores (mm).

NOTE This formula is independent of the metals used for the screens and for the oil ducts.

4.1.2.4.3 Three-core cables with circular conductors, metal tape core screens, without fillers and oil ducts, having a copper woven fabric tape binding the cores together and a corrugated aluminium sheath

The thermal resistance T_1 between one conductor and the sheath is given by:

$$T_1 = \frac{475}{D_c^{1{,}74}} \left[\frac{t_g}{D_c} \right]^{0{,}62} + \frac{\rho_T}{2\pi} \ln \left(\frac{d_c - 2\,\delta_1}{d_c} \right)$$

where

$$t_g = 0{,}5 \left(\left[\frac{D_{it} + D_{ic}}{2} \right] - 2{,}16\, D_c \right)$$

D_c is the diameter of a core over its metallic screen tapes (mm);

t_g is the average nominal clearance between the core metallic screen tapes and the average inside diameter of the sheath (mm);

δ_1 is the thickness of metallic tape core screen (mm).

NOTE The formula is independent of the metal used for the screen tapes.

4.1.2.5 SL and SA type cables

An SL or SA type cable is a three-core cable where each core has an individual lead or aluminium sheath. The sheath is considered to be sufficiently substantial so as to provide an isotherm at the outer surface of the insulation.

The thermal resistance T_1 is calculated in the same way as for single-core cables.

4.1.3 Thermal resistance between sheath and armour T_2

4.1.3.1 Single-core, two-core and three-core cables having a common metallic sheath

The thermal resistance between sheath and armour, T_2, is given by:

$$T_2 = \frac{1}{2\pi} \rho_T \ln\left[1 + \frac{2\,t_2}{D_s}\right]$$

where

t_2 is the thickness of the bedding (mm);

D_s is the external diameter of the sheath (mm).

NOTE For unarmoured cables with extruded insulation where each core has an individual screen of spaced wires and for unarmoured cables with a common metallic screen over all three cores T_2 = 0.

4.1.3.2 SL and SA type cables

The thermal resistance of fillers and bedding under the armour is given by:

$$T_2 = \frac{\rho_T}{6\pi} \overline{G}$$

where

$\overline{G}$ is the geometric factor given in Figure 6.

4.1.4 Thermal resistance of outer covering (serving) T_3

4.1.4.1 General case

The external servings are generally in the form of concentric layers and the thermal resistance T_3 is given by:

$$T_3 = \frac{1}{2\pi} \rho_T \ln\left(1 + \frac{2\,t_3}{D'_a}\right)$$

where

t_3 is the thickness of serving (mm);

D'_a is the external diameter of the armour (mm).

NOTE For unarmoured cables D'_a is taken as the external diameter of the component immediately beneath it, i.e. sheath, screen or bedding.

For corrugated sheaths:

$$T_3 = \frac{1}{2\pi}\rho_T \ln\left[\frac{D_{oc} + 2\,t_3}{\left(\frac{D_{oc} + D_{it}}{2}\right) + t_s}\right]$$

4.1.4.2 Unarmoured three-core cables with extruded insulation and individual copper tape screens on each core

The thermal resistance of the fillers, binder and external serving is given by:

$$T_3 = \frac{\rho_T}{2\pi}\ln\left(1 + \frac{2t_3}{D'_a}\right) + \frac{\rho_f}{6\pi}\overline{G}$$

where

ρ_f is the thermal resistivity of filler (K·m/W);

$\overline{G}$ is the geometric factor given in Figure 6 based on the thickness of material between the copper tape screen and the outer covering (serving);

D'_a is taken as the diameter over the binder tape.

4.1.5 Pipe-type cables

For these three-core cables, we have:

a) The thermal resistance T_1 of the insulation of each core between the conductor and the screen. This is calculated by the method set out in 4.1.2 for single-core cables.

b) The thermal resistance T_2 is made up of two parts:

   1) The thermal resistance of any serving over the screen or sheath of each core. The value to be substituted for part of T_2 in the rating equation of 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014 is the value per cable, i.e. the value for a three-core cable is one-third the value of a single core.

      The value per core is calculated by the method given in 4.1.3 for the bedding of single-core cables. For oval cores, the geometric mean of the major and minor diameter $\sqrt{d_M \cdot d_m}$ shall be used in place of the diameter for a circular core assembly.

   2) The thermal resistance of the gas or oil between the surface of the cores and the pipe. This resistance is calculated in the same way as that part of T_4 which is between a cable and the internal surface of a duct, as given in 4.2.7.2.

      The value calculated will be per cable and should be added to the quantity calculated in 4.1.5 b)1) above, before substituting for T_2 in the rating equation of 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014.

c) The thermal resistance T_3 of any external covering on the pipe is dealt with as in 4.1.4. The thermal resistance of the metallic pipe itself is negligible.

4.2 External thermal resistance T_4

4.2.1 Cables laid in free air

4.2.1.1 Cables protected from direct solar radiation

The thermal resistance T_4 of the surroundings of a cable in air and protected from solar radiation is given by the formula:

$$T_4 = \frac{1}{\pi D_e^* h (\Delta\theta_s)^{1/4}}$$

where

$$h = \frac{Z}{(D_e^*)^g} + E$$

D_e^* is the external diameter of cable (m)

for corrugated sheaths $D_e^* = (D_{oc} + 2\ t_3) \cdot 10^{-3}$ (m);

NOTE Throughout 4.2.1 D_e^* is expressed in metres.

h is the heat dissipation coefficient obtained either from the above formula using the appropriate values of constants Z, E and g given in Table 2, or from the curves in Figures 7, 8 and 9, which are reproduced for convenience (W/m² $(K)^{5/4}$);

served cables and cables having a non-metallic surface should be considered to have a black surface. Unserved cables, either plain lead or armoured should be given a value of h equal to 88 % of the value for a black surface;

$\Delta\theta_s$ is the excess of cable surface temperature above ambient temperature (see hereinafter for method of calculation) *(K).*

For cables in unfilled troughs, see 4.2.6.

Calculation of $(\Delta\theta_s)^{1/4}$:

A simple iterative method of calculating $(\Delta\theta_s)^{1/4}$ is given below. The alternative graphical method is described in 5.7.

Calculate

$$K_A = \frac{\pi D_e^* h}{(1+\lambda_1+\lambda_2)}\left[\frac{T_1}{n} + T_2\ (1+\lambda_1) + T_3\ (1+\lambda_1+\lambda_2)\right]$$

then

$$(\Delta\theta_s)_{n+1}^{1/4} = \left[\frac{\Delta\theta + \Delta\theta_d}{1 + K_A\ (\Delta\theta_s)_n^{1/4}}\right]^{0,25}$$

Set the initial value of $(\Delta\theta_s)^{1/4} = 2$ and reiterate until $(\Delta\theta_s)_{n+1}^{1/4} - (\Delta\theta_s)_n^{1/4} \le 0{,}001$

where

$$\Delta\theta_d = W_d\left[\left(\frac{1}{1+\lambda_1+\lambda_2} - \frac{1}{2}\right)T_1 - \frac{n\,\lambda_2\,T_2}{1+\lambda_1+\lambda_2}\right]$$

This is a factor, having the dimensions of temperature difference, accounts for the dielectric losses. If the dielectric losses are neglected, $\Delta\theta_d = 0$.

$\Delta\theta$ is the permissible conductor temperature rise above ambient temperature.

4.2.1.2 Cables directly exposed to solar radiation – External thermal resistance T_4^*

Where cables are directly exposed to solar radiation, T_4^* is calculated by the method given in 4.2.1.1 except that in the iterative method $(\Delta\theta_s)^{1/4}$ is calculated using the following formula:

$$(\Delta\theta_s)_{n+1}^{1/4} = \left[\frac{\Delta\theta + \Delta\theta_d + \Delta\theta_{ds}}{1 + K_A \; (\Delta\theta_s)_n^{1/4}} \right]^{0,25}$$

where

$$\Delta\theta_{ds} = \frac{\sigma \, D_e^* \, H}{(1+\lambda_1+\lambda_2)} \left[\frac{T_1}{n} + T_2 \; (1+\lambda_1) + T_3 \; (1+\lambda_1+\lambda_2) \right]$$

This is a factor which, having the dimensions of temperature difference, accounts for direct solar radiation.

where

σ is the absorption coefficient of solar radiation for the cable surface (see Table 3);

H is the intensity of solar radiation which should be taken as 10^3 W/m² for most latitudes; it is recommended that the local value should be obtained where possible;

D_e^* is the external diameter of cable (m)
for corrugated sheaths $D_e^* = (D_{oc} + 2\, t_3) \cdot 10^{-3}$ (m).

The alternative graphical method is included in Figure 10.

4.2.2 Single isolated buried cable

$$T_4 = \frac{1}{2\pi} \rho_T \ln\left(u + \sqrt{u^2 - 1} \right)$$

where

ρ_T is the thermal resistivity of the soil (K·m/W);

$u = \dfrac{2L}{D_e}$;

L is the distance from the surface of the ground to the cable axis (mm);

D_e is the external diameter of the cable (mm)
for corrugated sheaths $D_e = D_{oc} + 2\, t_3$.

When the value of u exceeds 10, a good approximation (closer than 1 part in 1 000) is:

$$T_4 = \frac{1}{2\pi} \rho_T \ln(2u)$$

For cable circuits installed at laying depths of more than 10 m, an alternative approach for calculating the current rating is to determine the continuous current rating for a designated time period (usually 40 years) by applying the formulae given in IEC 60853-2, taking into account as far as is practical seasonal variations in load and ground conditions, if any. Finite element modelling may provide a more versatile model for such a lifetime assessment. This subject is under consideration.

4.2.3 Groups of buried cables (not touching)

4.2.3.1 General

Such cases may be solved by using superposition, assuming that each cable acts as a line source and does not distort the heat field due to the other cables.

These cables are of two main types: the first, and most general type, is a group of unequally loaded cables of different construction, and for this problem a general indication of the method only can be given. The second type, which is a more particular one, is a group of equally loaded identical cables, and for this problem a fairly simple solution can be derived.

4.2.3.2 Unequally loaded cables

The method suggested for groups of unequally loaded dissimilar cables is to calculate the temperature rise at the surface of the cable under consideration caused by the other cables of the group, and to subtract this rise from the value of $\Delta\theta$ used in the equation for the rated current in 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014. An estimate of the power dissipated per unit length of each cable shall be made beforehand, and this can be subsequently amended as a result of the calculation where this becomes necessary.

Thus, the temperature rise $\Delta\theta_p$ above ambient at the surface of the p^{th} cable, whose rating is being determined, caused by the power dissipated by the other (q – 1) cables in the group, is given by:

$$\Delta\theta_p = \Delta\theta_{1p} + \Delta\theta_{2p} + \dots \Delta\theta_{kp} + \dots \Delta\theta_{qp}$$

(the term $\Delta\theta_{pp}$ is excluded from the summation)

where

$\Delta\theta_{kp}$ is the temperature rise at the surface of the cable produced by the power W_k watt per unit length dissipated in cable k:

$$\Delta\theta_{kp} = \frac{1}{2\pi}\, \rho_T\, W_k\, \ln\left(\frac{d'_{pk}}{d_{pk}}\right)$$

The distances d_{pk} and d'_{pk} are measured from the centre of the p^{th} cable to the centre of cable k, and to the centre of the reflection of cable k in the ground-air surface respectively (see Figure 1).

The value of $\Delta\theta$ in the equation for the rated current in 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014 is then reduced by the amount $\Delta\theta_p$ and the rating of the p^{th} cable is determined using a value T_4 corresponding to an isolated cable at position p.

This calculation is performed for all cables in the group and is repeated where necessary to avoid the possibility of overheating any cable.

4.2.3.3 Equally loaded identical cables

4.2.3.3.1 General

The second type of grouping is where the rating of a number of equally loaded identical cables is determined by the rating of the hottest cable. It is usually possible to decide from the configuration of the installation which cable will be the hottest, and to calculate the rating for this one. In cases of difficulty, a further calculation for another cable may be necessary. The method is to calculate a modified value of T_4 which takes into account the mutual heating of the group and to leave unaltered the value of $\Delta\theta$ used in the rating equation of 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014.

The modified value of the external thermal resistance T_4 of the p^{th} cable is given by:

$$T_4 = \frac{1}{2\pi}\rho_T \ln\left\{\left(u+\sqrt{u^2-1}\right)\left[\left(\frac{d'_{p1}}{d_{p1}}\right)\left(\frac{d'_{p2}}{d_{p2}}\right)\cdots\left(\frac{d'_{pk}}{d_{pk}}\right)\cdots\left(\frac{d'_{pq}}{d_{pq}}\right)\right]\right\}$$

There are (q – 1) terms, with the term $\frac{d'_{pp}}{d_{pp}}$ excluded.

The distances d_{pk}, etc., are the same as those shown in Figure 1, for the first method.

The simpler version 2 u may be used instead of $u+\sqrt{u^2-1}$ if suitable (see 4.2.2).

For simple configurations of cables, this formula may be simplified considerably. The following examples were obtained by the use of superposition.

4.2.3.3.2 Two cables having equal losses, laid in a horizontal plane, spaced apart

$$T_4 = \frac{1}{2\pi}\rho_T\left\{\ln\left(u+\sqrt{u^2-1}\right)+\frac{1}{2}\ln\left[1+\left(\frac{2L}{s_1}\right)^2\right]\right\}$$

where

$u = \frac{2L}{D_e}$;

L is the distance from the surface of the ground to the cables axis (mm);

D_e is the external diameter of one cable (mm);

s_1 is the axial separation between two adjacent cables (mm).

When the value of u exceeds 10, the term ($u+\sqrt{u^2-1}$) may be replaced by (2 u).

4.2.3.3.3 Three cables having approximately equal losses, laid in a horizontal plane; equally spaced apart

$$T_4 = \frac{1}{2\pi}\rho_T\left\{\ln\left(u+\sqrt{u^2-1}\right)+\ln\left[1+\left(\frac{2L}{s_1}\right)^2\right]\right\}$$

The value T_4 is that of the centre cable of the group and is used directly in the equation of 1.4.1 of IEC 60287-1-1:2006.

4.2.3.3.4 Three cables having unequal sheath losses, laid in a horizontal plane; equally spaced apart

When the losses in the sheaths of single-core cables laid in a horizontal plane are appreciable, and the sheaths are laid without transposition and/or the sheaths are bonded at all joints, their inequality affects the external thermal resistances of the hottest cable. In such cases the value of T_4 to be used in the numerator of the rating equation in 1.4.1 of IEC 60287-1-1:2006 is as given in 4.2.3.3.3, but a modified value of T_4 shall be used in the denominator, and is given by:

$$T_4 = \frac{1}{2\pi}\rho_T \left\{ \ln\left(u + \sqrt{u^2 - 1}\right) + \left[\frac{1 + 0{,}5(\lambda'_{11} + \lambda'_{12})}{1 + \lambda'_{lm}}\right] \ln\left[1 + \left(\frac{2L}{s_1}\right)^2\right]\right\}$$

This assumes that the centre cable is the hottest cable. The value of λ_1 to be used in the rating equation of 1.4.1 of IEC 60287-1-1:2006 is that for the centre cable,

where

$u = \frac{2L}{D_e}$;

L is the distance from the surface of the ground to the cables axis (mm);

D_e is the external diameter of one cable (mm);

s_1 is the axial separation between two adjacent cables (mm);

λ'_{11} is the sheath loss factor for an outer cable of the group;

λ'_{12} is the sheath loss factor for the other outer cable of the group;

λ'_{lm} is the sheath loss factor for the middle cable of the group.

When the value of u exceeds 10, the term ($u + \sqrt{u^2 - 1}$) may be replaced by (2 u).

4.2.4 Groups of buried cables (touching) equally loaded

4.2.4.1 Two single-core cables, flat formation

4.2.4.1.1 Metallic sheathed cables

Metallic sheathed cables are taken to be cables where it can be assumed that there is a metallic layer that provides an isotherm at, or immediately under, the outer sheath of the cable.

$$T_4 = \frac{\rho_T}{\pi}\left(\ln(2u) - 0{,}451\right) \quad \text{for } u \geq 5$$

4.2.4.1.2 Non-metallic sheathed cables

Non-metallic sheathed cables are taken to be cables where any metallic layer at, or immediately under, the outer sheath of the cable is not sufficient to provide an isotherm.

$$T_4 = \frac{\rho_T}{\pi}\left(\ln(2u) - 0{,}295\right) \quad \text{for } u \geq 5$$

This formula is used for non-metallic sheathed cables having a copper wire screen and for the external thermal resistance of non-metallic touching ducts (see 4.2.7.4).

4.2.4.2 Three single-core cables, flat formation

4.2.4.2.1 Metallic sheathed cables

Metallic sheathed cables are taken to be cables where it can be assumed that there is a metallic layer that provides an isotherm at, or immediately under, the outer sheath of the cable. The value of λ_1 used in the rating equation of 1.4.1.1 of IEC 60287-1-1:2006 is the average of the λ_1 values for the three cables.

$$T_4 = \rho_T \left(0{,}475 \ \ln(2u) - 0{,}346\right) \quad \text{for } u \geq 5$$

4.2.4.2.2 Non-metallic sheathed cables

Non-metallic sheathed cables are taken to be cables where any metallic layer at, or immediately under, the outer sheath of the cable is not sufficient to provide an isotherm.

$$T_4 = \rho_T \left(0{,}475 \ \ln(2u) - 0{,}142\right) \quad \text{for } u \geq 5$$

This formula is used for non-metallic sheathed cables having a copper wire screen and for the external thermal resistance of non-metallic touching ducts (see 4.2.7.4).

4.2.4.3 Three single-core cables, trefoil formation

4.2.4.3.1 General

For this configuration, L is measured to the centre of the trefoil group and D_e is the diameter of one cable. T_4 is the external thermal resistance of any one of the cables and the configuration may be with the apex either at the top or at the bottom of the group.

For corrugated sheaths, $D_e = D_{oc} + 2\ t_3$.

4.2.4.3.2 Metallic sheathed cables

$$T_4 = \frac{1{,}5}{\pi} \rho_T \left[\ln(2u) - 0{,}630\right]$$

In this case, the thermal resistance of the serving over the sheath or armour, T_3, as calculated by the method given in 4.1.4 shall be multiplied by a factor of 1,6.

4.2.4.3.3 Part-metallic covered cables (where helically laid armour or screen wires cover from 20 % to 50 % of the cable circumference)

This formula is based on long lay (15 times the diameter under the wire screen) 0,7 mm diameter, individual copper wires having a total cross-sectional area of between 15 mm^2 and 35 mm^2.

$$T_4 = \frac{1{,}5}{\pi} \rho_T \left[\ln(2u) - 0{,}630\right]$$

In this case, the thermal resistance of the insulation T_1, as calculated by the method given in 4.1.2.1 and the thermal resistance of the serving T_3, as calculated by the method given in 4.1.3 shall be multiplied by the following factors:

T_1: by 1,07 for cables up to 35 kV

by 1,16 for cables from 35 kV to 150 kV

T_3: by 1,6.

4.2.4.3.4 Non-metallic sheathed cables

$$T_4 = \frac{1}{2\pi} \rho_T \left[\ln(2u) + 2\ln(u)\right]$$

This formula is used for non-metallic sheathed cables having a screen of spaced copper wires and for the external thermal resistance of touching ducts (see 4.2.7.4).

4.2.5 Buried pipes

The external thermal resistance of buried pipes used for pipe-type cables is calculated as for ordinary cables, using the formula in 4.2.2. In this case, the depth of laying L is measured to the centre of the pipe and D_e is the external diameter of the pipe, including anti-corrosion covering.

4.2.6 Cables in buried troughs

4.2.6.1 Buried troughs filled with sand

Where cables are installed in sand-filled troughs, either completely buried or with the cover flush with the ground surface, there is danger that the sand will dry out and remain dry for long periods. The cable external thermal resistance may then be very high and the cable may reach undesirably high temperatures. It is advisable to calculate the cable rating using a value of 2,5 K·m/W for the thermal resistivity of the sand filling unless a specially selected filling has been used for which the dry resistivity is known.

4.2.6.2 Unfilled troughs of any type, with the top flush with the soil surface and exposed to free air

An empirical formula is used which gives the temperature rise of the air in the trough above the air ambient as:

$$\Delta\theta_{tr} = \frac{W_{TOT}}{3\,p}$$

where

W_{TOT} is the total power dissipated in the trough per metre length (W/m);

p is that part of the trough perimeter which is effective for heat dissipation (m).

Any portion of the perimeter, which is exposed to sunlight, is therefore not included in the value of p. The rating of a particular cable in the trough is then calculated as for a cable in free air (see 4.2.1), but the ambient temperature shall be increased by $\Delta\theta_{tr}$.

4.2.7 Cables in ducts or pipes

4.2.7.1 General

The external thermal resistance of a cable in a duct consists of three parts.

a) The thermal resistance of the air space between the cable surface and duct internal surface T_4' .

b) The thermal resistance of the duct itself, T_4''. The thermal resistance of a metal pipe is negligible.

c) The external thermal resistance of the duct T_4''.

The value of T_4 to be substituted in the equation for the permissible current rating in 1.4 of IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014 will be the sum of the individual parts, i.e.:

$$T_4 = T_4' + T_4'' + T_4'''$$

Cables in ducts which have been completely filled with a pumpable material having a thermal resistivity not exceeding that of the surrounding soil, either in the dry state or when sealed to preserve the moisture content of the filling material, may be treated as directly buried cables.

4.2.7.2 Thermal resistance between cable and duct (or pipe) T_4'

For the cable diameters in the range 25 mm to 100 mm the following formula shall be used for ducted cable. It shall also be used for the thermal resistance of the space between cores and pipe surface of a pipe-type cable (see 4.1.5 b)), when the equivalent diameter of the three cores in the pipe is within the range 75 mm to 125 mm. The equivalent diameter is defined below:

$$T_4' = \frac{U}{1+0{,}1\,(V+Y\theta_m)\,D_e}$$

where

U, V, Y are constants, depending on the installations the values of which are given in Table 4;

D_e is the external diameter of the cable (mm);

when the formula is used for pipe-type cables (see 4.1.5 b)), D_e becomes the equivalent diameter of the group of cores as follows:

- two cores: D_e = 1,65 × core outside diameter (mm);
- three cores: D_e = 2,15 × core outside diameter (mm);
- four cores: D_e = 2,50 × core outside diameter (mm);

θ_m is the mean temperature of the medium filling the space between cable and duct. An assumed value has to be used initially and the calculation repeated with a modified value if necessary (°C).

4.2.7.3 Thermal resistance of the duct (or pipe) itself T_4''

The thermal resistance (T_4'') across the wall of a duct shall be calculated from:

$$T_4'' = \frac{1}{2\pi}\,\rho_T\,\ln\left(\frac{D_o}{D_d}\right)$$

where

D_o is the outside diameter of the duct (mm);

D_d is the inside diameter of the duct (mm);

ρ_T is the thermal resistivity of duct material (K·m/W).

The value of ρ_T can be taken as zero for metal ducts, for other materials, see Table 1.

4.2.7.4 External thermal resistance of the duct (or pipe) T_4'''

This shall be determined for single-way duct(s) not embedded in concrete in the same way as for cable, using the appropriate formulae given in 4.2.1, 4.2.2, 4.2.3 or 4.2.4, and the external radius of the duct or pipe including any protective covering thereon, replacing the external radius of the cable. When the ducts are embedded in concrete, the calculation of the thermal resistance outside the ducts is first of all made assuming a uniform medium outside the ducts having a thermal resistivity equal to the concrete. A correction is then added algebraically to take account of the difference, if any, between the thermal resistivities of concrete and soil for that part of the thermal circuit exterior to the duct bank.

The correction to the thermal resistance is given by:

$$\frac{N}{2\pi}\,(\rho_e-\rho_c)\,\ln\left(u+\sqrt{u^2-1}\right)$$

where

N is the number of loaded cables in the duct bank;

ρ_e is the thermal resistivity of earth around bank (K·m/W);

ρ_c is the thermal resistivity of concrete (K·m/W);

$u = \frac{L_G}{r_b}$

L_G is the depth of laying to centre of duct bank (mm);

r_b is the equivalent radius of concrete bank (mm) given by:

$$\ln r_b = \frac{1}{2}\frac{x}{y}\left(\frac{4}{\pi} - \frac{x}{y}\right)\ln\left(1+\frac{y^2}{x^2}\right) + \ln\frac{x}{2}$$

The quantities x and y are the shorter and longer sides, respectively, of the duct bank section irrespective of its position, in millimetres.

This formula is only valid for ratios of $\frac{y}{x}$ less than 3.

5 Digital calculation of quantities given graphically

5.1 General

Clause 5 gives formulae and methods suitable for digital calculation for those quantities given in Figures 2 to 6 and the procedure for calculating $\Delta\theta_s$ by means of Figure 10. The method used is approximation by algebraic expressions, followed by quadratic or linear interpolation where necessary. The maximum percentage error prior to interpolation is given for each case.

5.2 Geometric factor G for two-core belted cables with circular conductors

See Figure 2.

Denote $X = t_1/d_c$

$Y = (2t_1/t) - 1$

then $G = MG_s$

where

$$M = \text{formule Mie} = \ln\left[\frac{1-\alpha\beta+\left[(1-\alpha^2)(1-\beta^2)\right]^{0,5}}{\alpha-\beta}\right]$$

$$\alpha = \frac{1}{\left[1+\frac{X}{1+X/(1+Y)}\right]^2}$$

$$\frac{\beta}{\alpha} = \frac{\frac{X}{1+Y}-\frac{1}{2}}{\frac{X}{1+Y}+\frac{3}{2}}$$

$G_s = G_s\,(X, Y)$, i.e. is a function of both X and Y.

Calculate the three quantities G_s $(X, 0)$, G_s $(X, 0{,}5)$ and G_s $(X, 1)$

where:

$G_s (X, 0) = 1{,}060\ 19 - 0{,}067\ 177\ 8\ X + 0{,}017\ 952\ 1\ X^2$

$G_s (X, 0{,}5) = 1{,}067\ 98 - 0{,}065\ 164\ 8\ X + 0{,}015\ 812\ 5\ X^2$

$G_s (X, 1) = 1{,}067\ 00 - 0{,}055\ 715\ 6\ X + 0{,}012\ 321\ 2\ X^2$

G_s (X, Y) may be obtained by quadratic interpolation using the following formula:

$$G_s (X, Y) = G_s (X, 0) + Y [-3\ G_s (X, 0) + 4\ G_s (X, 0{,}5) - G_s (X, 1)] + Y^2 [2\ G_s (X, 0) - 4\ G_s (X, 0{,}5) + 2\ G_s (X, 1)]$$

The maximum percentage error in the calculation of G_s $(X, 0)$, G_s $(X, 0{,}5)$ and G_s $(X, 1)$ is less than 0,5 % compared with corresponding graphical values.

5.3 Geometric factor G for three-core belted cables with circular conductors

See Figure 3.

Denote $X = t_1/d_c$

$Y = (2t_1/t) - 1$

and $G = MG_s$

where

$$M = \text{formule Mie} = \ln\left[\frac{1-\alpha\beta+\left[(1-\alpha^2)(1-\beta^2)\right]^{0,5}}{\alpha-\beta}\right]$$

$$\alpha = \frac{1}{\left[1+\dfrac{2X}{1+\dfrac{2}{\sqrt{3}}\left(1+\dfrac{2X}{1+Y}\right)}\right]^3}$$

$$\frac{\beta}{\alpha} = \frac{\dfrac{2}{\sqrt{3}}\left(1+\dfrac{2X}{1+Y}\right)-3}{\dfrac{2}{\sqrt{3}}\left(1+\dfrac{2X}{1+Y}\right)+3}$$

$G_s = G_s$ (X, Y), i.e., is a function of both X and Y.

Calculate the three quantities G_s $(X, 0)$, G_s $(X, 0{,}5)$ and G_s $(X, 1)$

where

$G_s (X, 0) = 1{,}094\ 14 - 0{,}094\ 404\ 5\ X + 0{,}023\ 446\ 4\ X^2$

$G_s (X, 0{,}5) = 1{,}096\ 05 - 0{,}080\ 185\ 7\ X + 0{,}017\ 691\ 7\ X^2$

$G_s (X, 1) = 1{,}098\ 31 - 0{,}072\ 063\ 1\ X + 0{,}014\ 590\ 9\ X^2$

and obtain G_s (X, Y) by quadratic interpolation between the three calculated values.

This may be done by substituting G_s $(X, 0)$, G_s $(X, 0{,}5)$ and G_s $(X, 1)$ in the following formula:

$$G_s(X, Y) = G_s(X, 0) + Y\,[-3\,G_s(X, 0) + 4\,G_s(X, 0{,}5) - G_s(X, 1)] + Y^2\,[\,2\,G_s(X, 0) - 4\,G_s(X, 0{,}5) + 2\,G_s(X, 1)]$$

The maximum percentage error in the calculation of $G_s(X, 0)$, $G_s(X, 0{,}5)$ and $G_s(X, 1)$ is less than 0,5 % compared with corresponding graphical values.

5.4 Thermal resistance of three-core screened cables with circular conductors compared to that of a corresponding unscreened cable

See Figure 4.

Denote $X = (\delta_1\,\rho_T)/(d_c\,\rho_m)$

$Y = t_1/d_c$

The screening factor K is a function of both X and Y. Calculate the three quantities $K(X, 0{,}2)$, $K(X, 0{,}6)$ and $K(X, 1)$ from the following formulae according to whether $0 < X \le 6$ or $6 < X \le 25$.

$0 < X \le 6$

$$K(X, 0{,}2) = 0{,}998\,095 - 0{,}123\,369\,X + 0{,}020\,262\,0\,X^2 - 0{,}001\,416\,67\,X^3$$

$$K(X, 0{,}6) = 0{,}999\,452 - 0{,}089\,658\,9\,X + 0{,}012\,023\,9\,X^2 - 0{,}000\,722\,228\,X^3$$

$$K(X, 1) = 0{,}997\,976 - 0{,}052\,857\,1\,X + 0{,}003\,452\,38\,X^2$$

$6 < X \le 25$

$$K(X, 0{,}2) = 0{,}824\,160 - 0{,}028\,872\,1\,X + 0{,}000\,928\,511\,X^2 - 0{,}000\,013\,712\,1\,X^3$$

$$K(X, 0{,}6) = 0{,}853\,348 - 0{,}024\,687\,4\,X + 0{,}000\,966\,967\,X^2 - 0{,}000\,015\,996\,7\,X^3$$

$$K(X, 1) = 0{,}883\,287 - 0{,}015\,378\,2\,X + 0{,}000\,260\,292\,X^2$$

$K(X, Y)$ is then obtained by quadratic interpolation between the three calculated values. This may be done by substitution in the following formula:

$$K(X, Y) = K(X, 0{,}2) + Z\,[-3\,K(X, 0{,}2) + 4\,K(X, 0{,}6) - K(X, 1)] + Z^2\,[\,2\,K(X, 0{,}2) - 4\,K(X, 0{,}6) + 2\,K(X, 1)]$$

where $Z = 1{,}25\,Y - 0{,}25$

The maximum percentage error in the calculation of the sector correction factor is less than 0,5 % compared with graphical values.

5.5 Thermal resistance of three-core screened cables with sector-shaped conductors compared to that of a corresponding unscreened cable

See Figure 5.

Denote $X = (\delta_1\,\rho_T)/(d_x\,\rho_m)$

$Y = t_1/d_x$

The screening factor K is a function of both X and Y. Calculate the three quantities $K(X, 0{,}2)$, $K(X, 0{,}6)$ and $K(X, 1)$ from the following formulae according to whether $0 < X \le 3$, $3 < X \le 6$, or $6 < X \le 25$.

$0 < X \le 3$

$$K(X, 0{,}2) = 1{,}001\,69 - 0{,}094\,5\,X + 0{,}007\,523\,81\,X^2$$

$$K(X, 0{,}6) = 1{,}001\,71 - 0{,}076\,928\,6\,X + 0{,}005\,357\,14\,X^2$$

$$K(X, 1) = K(X, 0{,}6)$$

$3 < X \leq 6$ $K(X, 0{,}2)$ and $K(X, 0{,}6)$ are given by the same formula as for $0 < X \leq 3$

$K(X, 1) = 1{,}001\,17 - 0{,}075\,214\,3\,X + 0{,}005\,333\,34\,X^2$

$6 < X \leq 25$ $K(X, 0{,}2) = 0{,}811\,646 - 0{,}023\,841\,3\,X + 0{,}000\,994\,933\,X^2 - 0{,}000\,015\,515\,2\,X^3$

$K(X, 0{,}6) = 0{,}833\,598 - 0{,}022\,315\,5\,X + 0{,}000\,978\,956\,X^2 - 0{,}000\,015\,831\,1\,X^3$

$K(X, 1) = 0{,}842\,875 - 0{,}022\,725\,5\,X + 0{,}001\,058\,25\,X^2 - 0{,}000\,017\,742\,7\,X^3$

For $0 < X \leq 3$ and $0{,}2 < Y \leq 0{,}6$, $K(X, Y)$ is obtained by linear interpolation between $K(X, 0{,}2)$ and $K(X, 0{,}6)$ as follows:

$$K(X, Y) = K(X, 0{,}2) + 2{,}5\,(Y - 0{,}2)\,[K(X, 0{,}6) - K(X, 0{,}2)]$$

For $3 < X < 25$, $K(X, Y)$ is obtained by quadratic interpolation between the three calculated values. The relevant formula is:

$$K(X, Y) = K(X, 0{,}2) + Z\,[-3\,K(X, 0{,}2) + 4\,K(X, 0{,}6) - K(X, 1)] + Z^2\,[2\,K(X, 0{,}2) - 4\,K(X, 0{,}6) + 2\,K(X, 1)]$$

where $Z = 1{,}25\,Y - 0{,}25$

The maximum percentage error in the calculation of the sector correction factor is less than 1 % compared with graphical values.

5.6 Curve for $\overline{G}$ for obtaining the thermal resistance of the filling material between the sheaths and armour of SL and SA type cables

See Figure 6.

Denote X = thickness of material between sheaths and armour expressed as a fraction of the outer diameter of the sheath.

The lower curve is given by:

$0 < X \leq 0{,}03$ $\overline{G} = 2\pi\,(0{,}000\,202\,380 + 2{,}032\,14\,X - 21{,}666\,7\,X^2)$

$0{,}03 < X \leq 0{,}15$ $\overline{G} = 2\pi\,(0{,}012\,652\,9 + 1{,}101\,X - 4{,}561\,04\,X^2 + 11{,}509\,3\,X^3)$

The maximum percentage error in the calculation of $\overline{G}$ is less than 1 %.

The upper curve is given below:

$0 < X \leq 0{,}03$ $\overline{G} = 2\pi\,(0{,}000\,226\,19 + 2{,}114\,29\,X - 20{,}476\,2\,X^2)$

$0{,}03 < X \leq 0{,}15$ $\overline{G} = 2\pi\,(0{,}014\,210\,8 + 1{,}175\,33\,X - 4{,}497\,37\,X^2 + 10{,}635\,2\,X^3)$

The maximum percentage error in the calculation of $\overline{G}$ is less than 1 %.

5.7 Calculation of $\Delta\theta_s$ by means of a diagram

See Figure 10.

The procedure is as follows:

a) calculate the value of K_A using the formula:

$$K_A = \frac{\pi D_e^* h}{1+\lambda_1+\lambda_2}\left[\frac{T_1}{n} + T_2\,(1+\lambda_1) + T_3\,(1+\lambda_1+\lambda_2)\right]$$

b) locate the line on Figure 10 with the value of a) above as ordinate, and then locate the point on this line for the appropriate value of:

$$\Delta\theta + \Delta\theta_d + \Delta\theta_{ds} = \text{constant}$$

c) read off the abscissa of this point to obtain:

$$(\Delta\theta_s)^{1/4}$$

1) cables protected from solar radiation

$$\Delta\theta_d = W_d\left[\left(\frac{1}{1+\lambda_1+\lambda_2} - \frac{1}{2}\right)T_1 - \frac{n\lambda_2\,T_2}{1+\lambda_1+\lambda_2}\right]$$

if the dielectric losses are neglected, $\Delta\theta_d = 0$
$\Delta\theta_{ds} = 0$

2) cables subjected to solar radiation

$$\Delta\theta_d = W_d\left[\left(\frac{1}{1+\lambda_1+\lambda_2} - \frac{1}{2}\right)T_1 - \frac{n\lambda_2\,T_2}{1+\lambda_1+\lambda_2}\right]$$

if the dielectric losses are neglected, $\Delta\theta_d = 0$

$$\Delta\theta_{ds} = \sigma D_e^*\,H\left[\frac{T_1 + n\,(1+\lambda_1)\,T_2 + n\,(1+\lambda_1+\lambda_2)\,T_3}{n\,(1+\lambda_1+\lambda_2)}\right]$$

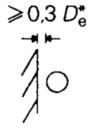
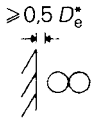
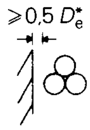
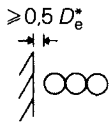
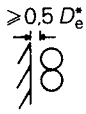
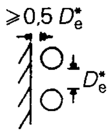
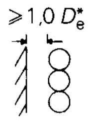
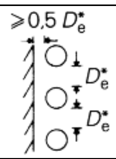
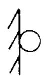
Table 1 – Thermal resistivities of materials

Material	**Thermal resistivity (ρ_T)** K·m/W
Insulating materials[a]	
Paper insulation in solid type cables	6,0
Paper insulation in oil-filled cables	5,0
Paper insulation in cables with external gas pressure	5,5
Paper insulation in cables with internal gas pressure:	
a) pre-impregnated	5,5
b) mass-impregnated	6,0
PE	3,5
XLPE	3,5
PPL	5,5
Polyvinyl chloride:	
up to and including 3 kV cables	5,0
greater than 3 kV cables	6,0
EPR:	
up to and including 3 kV cables	3,5
greater than 3 kV cables	5,0
Butyl rubber	5,0
Rubber	5,0
Protective coverings	
Compounded jute and fibrous materials	6,0
Rubber sandwich protection	6,0
Polychloroprene	5,5
PVC:	
up to and including 35 kV cables	5,0
greater than 35 kV cables	6,0
PVC/bitumen on corrugated aluminium sheaths	6,0
PE	3,5
Materials for duct installations	
Concrete	1,0
Fibre	4,8
Asbestos	2,0
Earthenware	1,2
PVC	6,0
PE	3,5

[a] For the purposes of current rating calculations, the semiconducting screening materials are assumed to have the same thermal properties as the adjacent dielectric materials.

Where plastic or elastomeric materials are used for protective coverings, the thermal resistivities shall be taken to be the same as those for the insulating grades of the materials given in this table.

Table 2 – Values for constants *Z*, *E* and *g* for black surfaces of cables in free air

No.	Installation	*Z*	*E*	*d*	Mode
Installation on non-continuous brackets, ladder supports or cleats, D_e^* not greater than 0,15 m					
1	Single cable[a]	0,21	3,94	0,60	
2	Two cables touching, horizontal	0,29	2,35	0,50	
3	Three cables in trefoil	0,96	1,25	0,20	
4	Three cables touching, horizontal	0,62	1,95	0,25	
5	Two cables touching, vertical	1,42	0,86	0,25	
6	Two cables spaced, D_e^* vertical	0,75	2,80	0,30	
7	Three cables touching, vertical	1,61	0,42	0,20	
8	Three cables spaced, D_e^* vertical	1,31	2,00	0,20	
Installation clipped direct to a vertical wall (D_e^* not greater than 0,08 m)					
9	Single cable	1,69	0,63	0,25	
10	Three cables in trefoil	0,94	0,79	0,20	

[a] Values for a “single cable” also apply to each cable of a group when they are spaced horizontally with a clearance between cables of at least 0,75 times the cable overall diameter.

Table 3 – Absorption coefficient of solar radiation for cable surfaces

Material	σ
Bitumen/jute serving	0,8
Polychloroprene	0,8
PVC	0,6
PE	0,4
Lead	0,6

Table 4 – Values of constants *U, V* and *Y*

Installation condition	*U*	*V*	*Y*
In metallic conduit	5,2	1,4	0,011
In fibre duct in air	5,2	0,83	0,006
In fibre duct in concrete	5,2	0,91	0,010
In asbestos cement:			
duct in air	5,2	1,2	0,006
duct in concrete	5,2	1,1	0,011
Gas pressure cable in pipe	0,95	0,46	0,002 1
Oil pressure pipe-type cable	0,26	0,0	0,002 6
Plastic ducts	1,87	0,312	0,003 7
Earthenware ducts	1,87	0,28	0,003 6
Water filled ducts	0,1	0,03	0,001

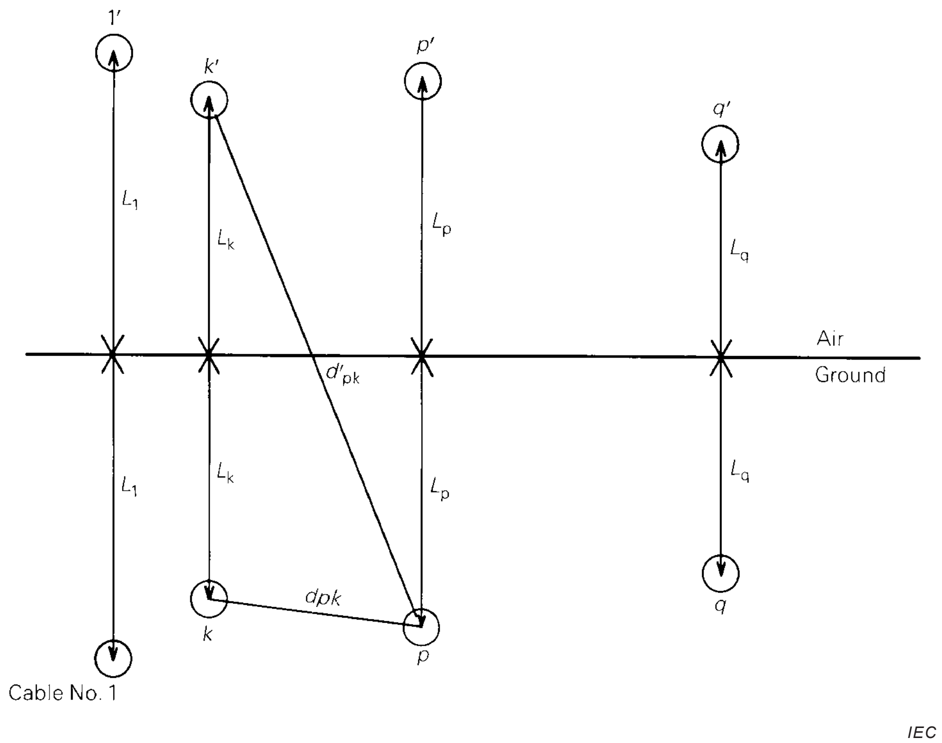


Figure 1 – Diagram showing a group of *q* cables and their reflection in the ground-air surface

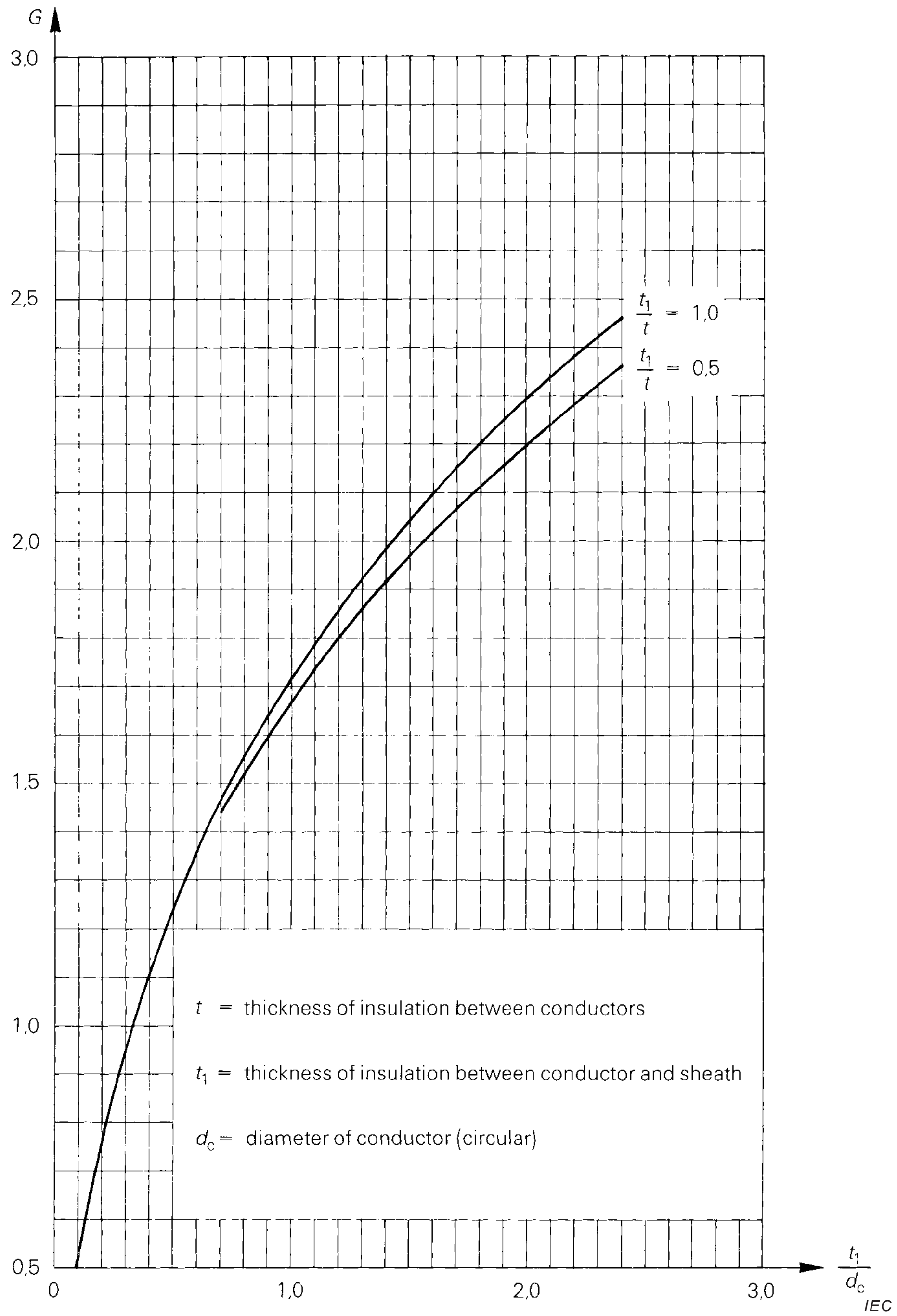


Figure 2 – Geometric factor *G* for two-core belted cables with circular conductors (see 4.1.2.2.2)

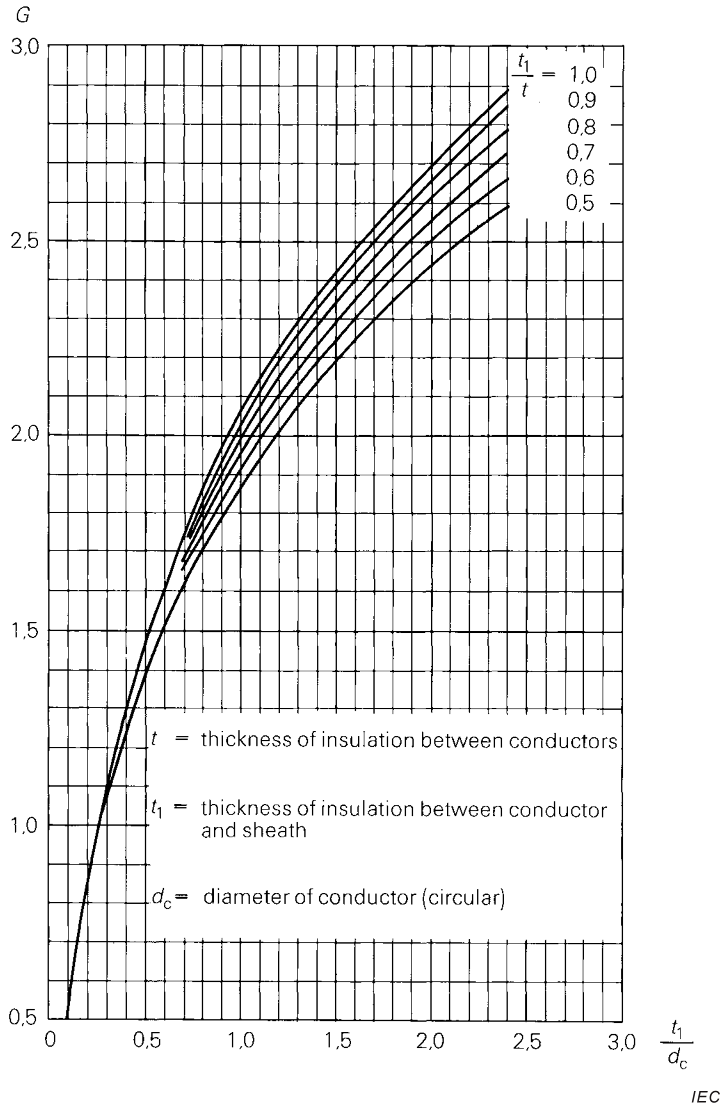


Figure 3 – Geometric factor *G* for three-core belted cables with circular conductors (see 4.1.2.2.4)

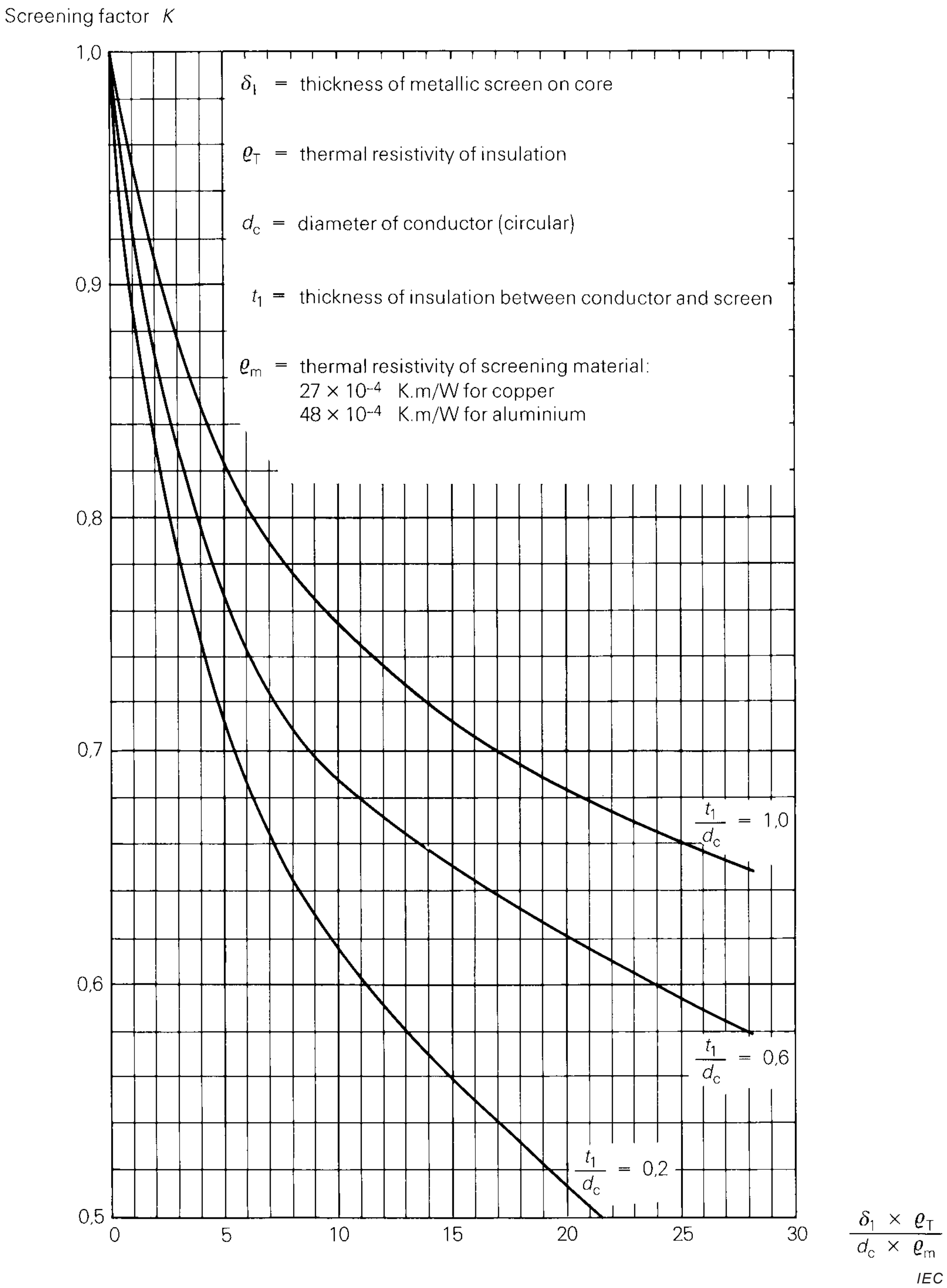


Figure 4 – Thermal resistance of three-core screened cables with circular conductors compared to that of a corresponding unscreened cable (see 4.1.2.3.1)

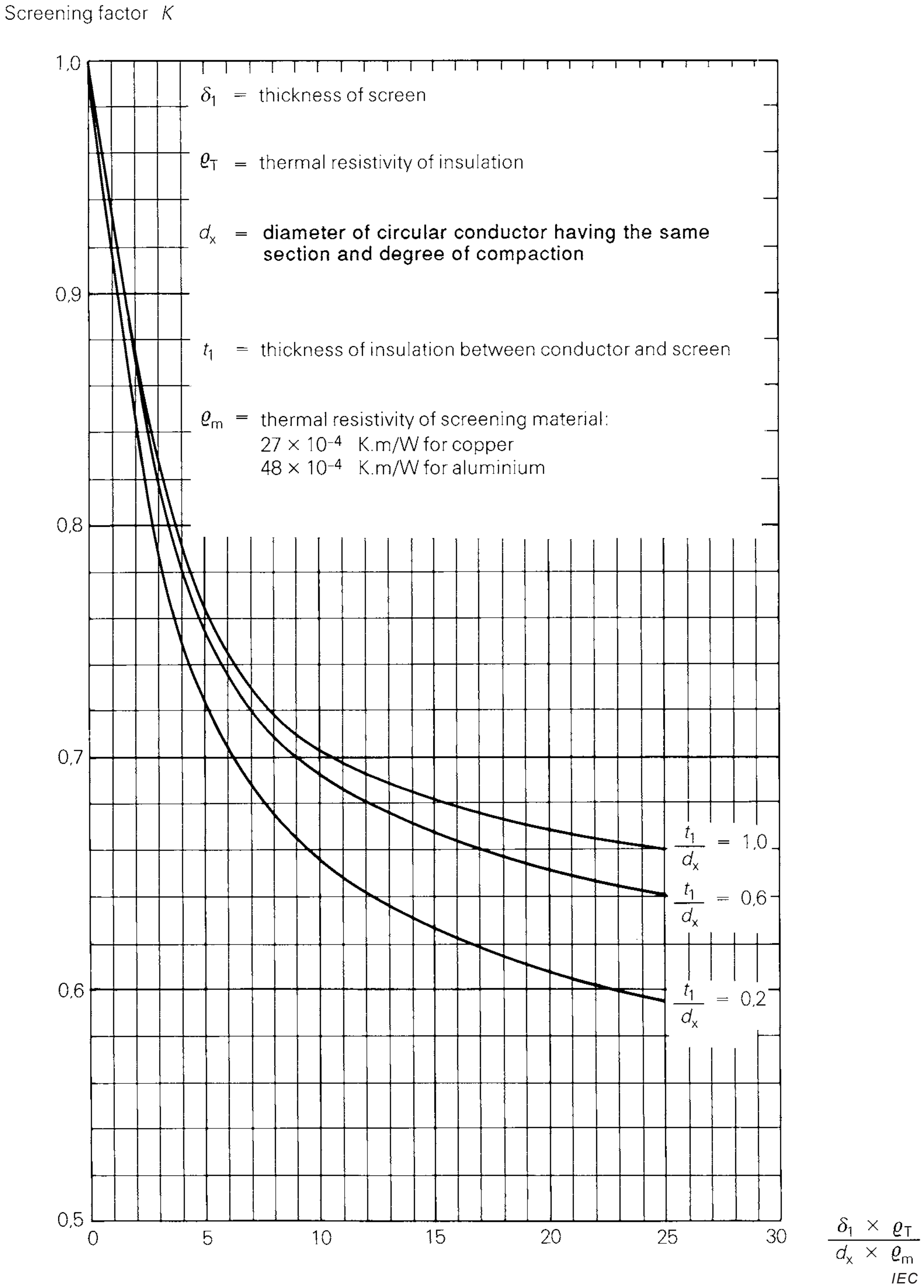


Figure 5 – Thermal resistance of three-core screened cables with sector-shaped conductors compared with that of a corresponding unscreened cable (see 4.1.2.3.3)

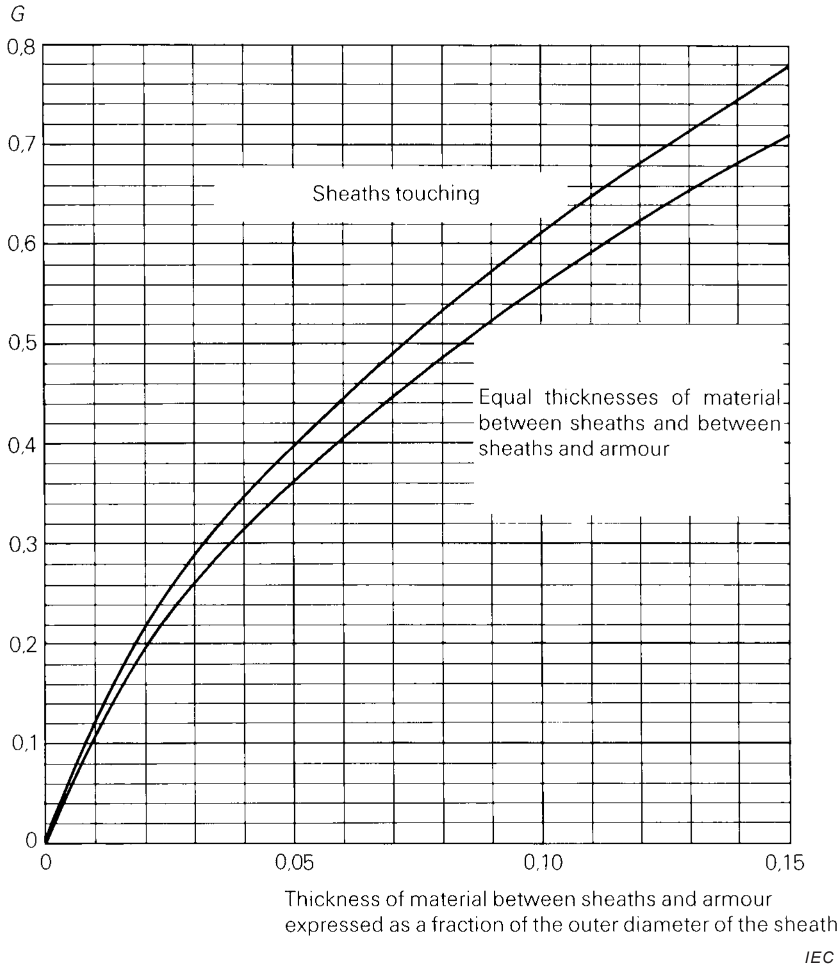


Figure 6 – Geometric factor $\overline{G}$ for obtaining the thermal resistances of the filling material between the sheaths and armour of SL and SA type cables (see 4.1.3.2)

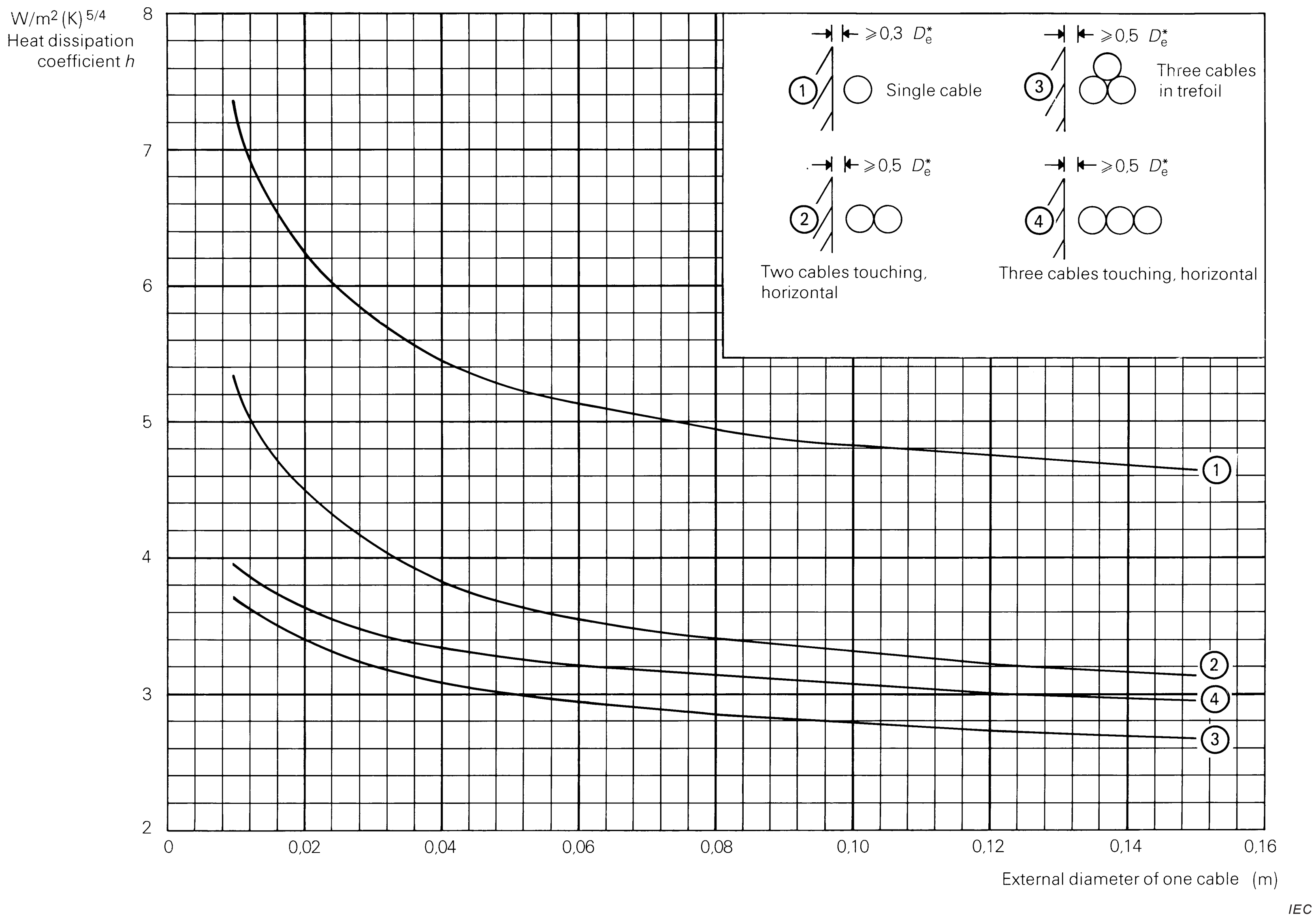


Figure 7 – Heat dissipation coefficient for black surfaces of cables in free air, laying condition #1 to #4

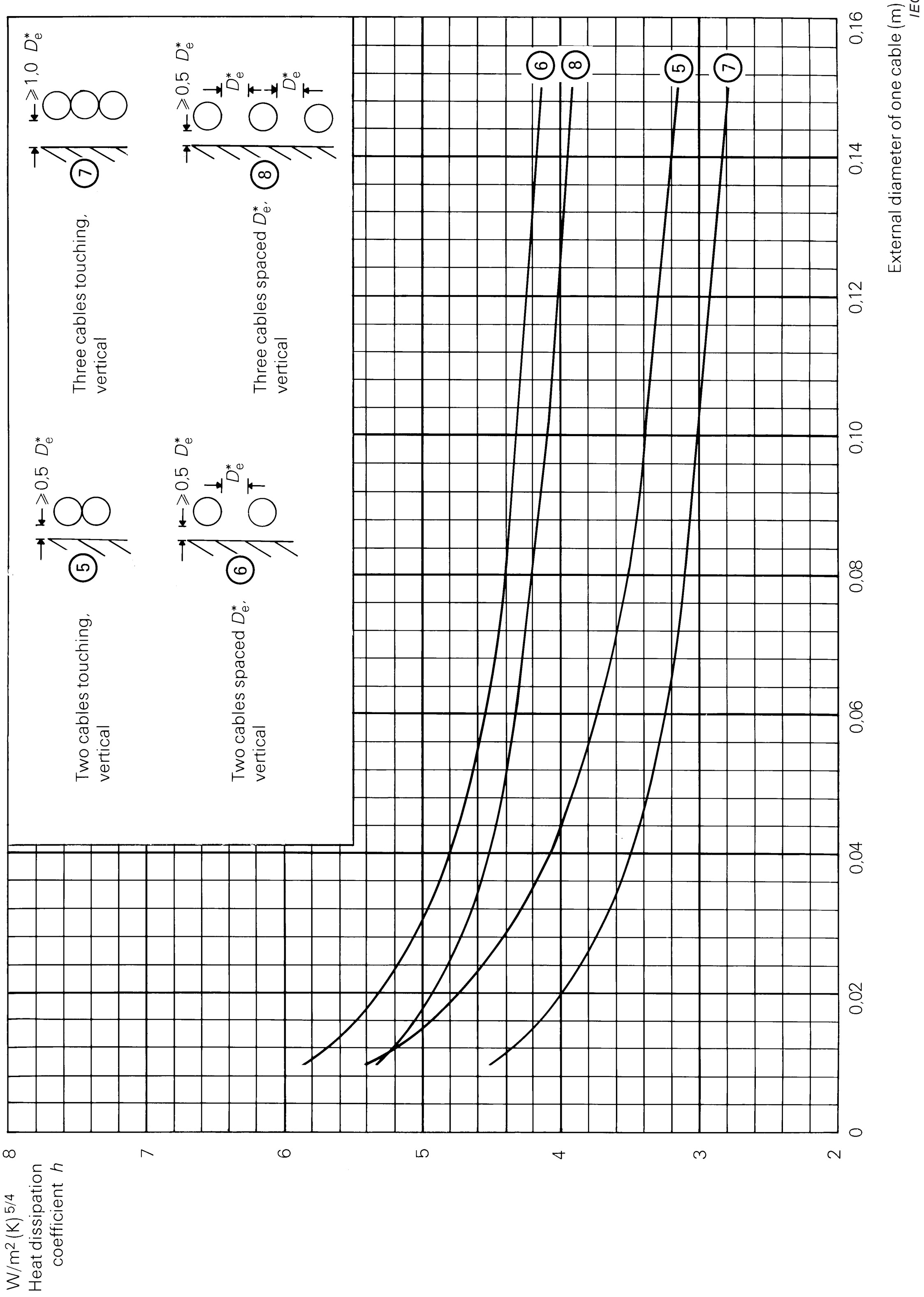


Figure 8 – Heat dissipation coefficient for black surfaces of cables in free air, laying condition #5 to #8

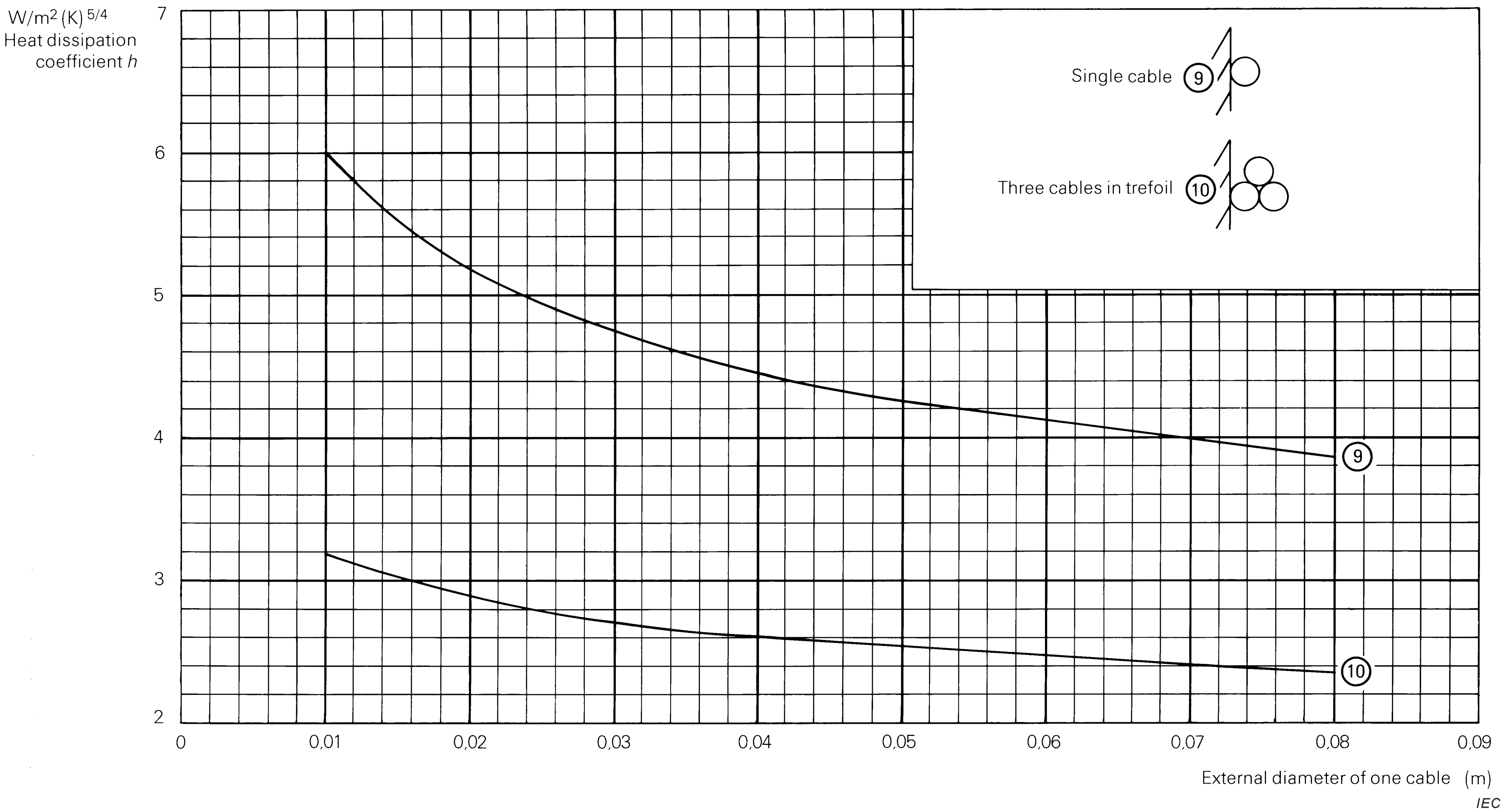


Figure 9 – Heat dissipation coefficient for black surfaces of cables in free air, laying condition #9 to #10

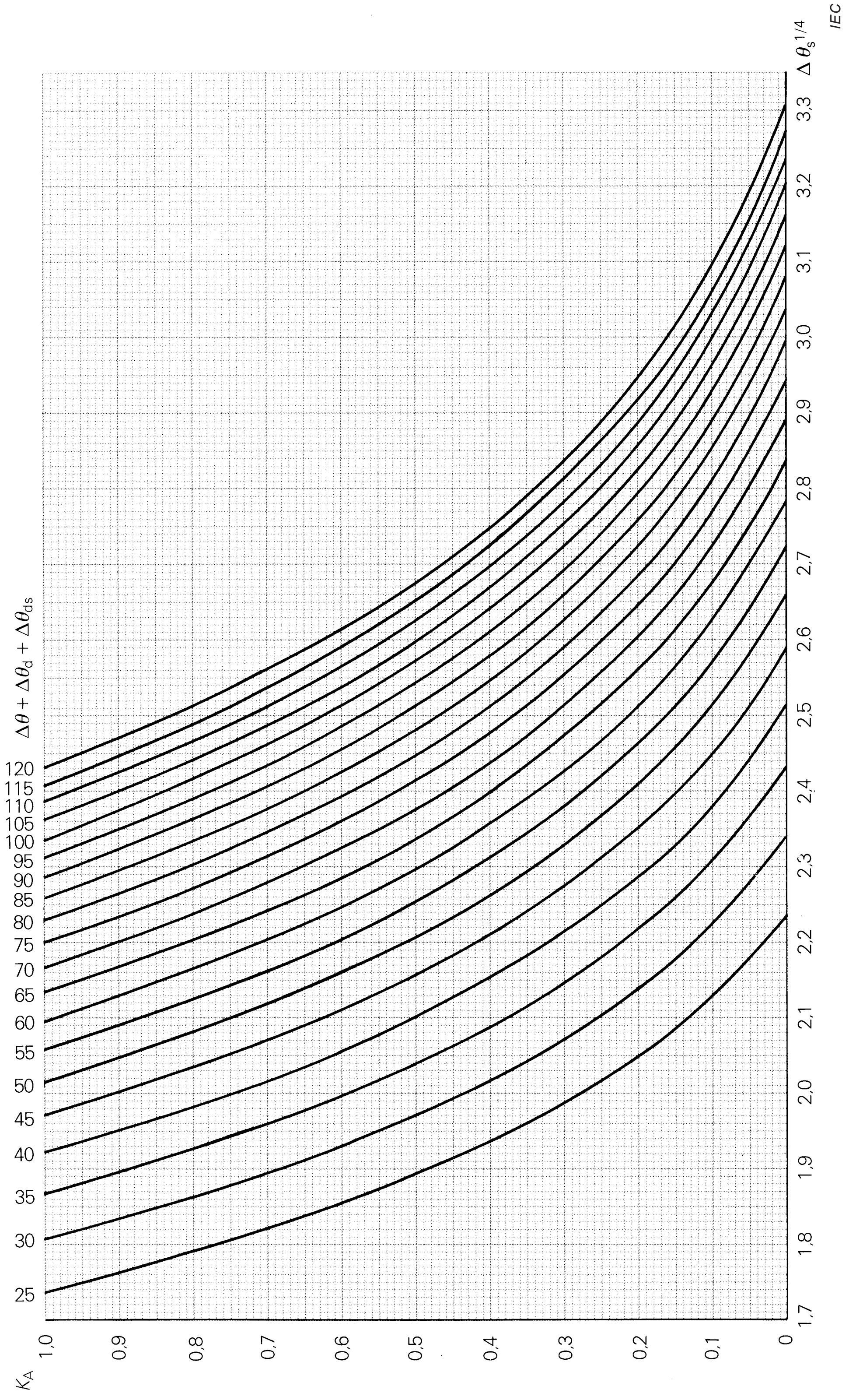


Figure 10 – Graph for the calculation of external thermal resistance of cables in air

Bibliography

IEC 60287-3-1, *Electric cables – Calculation of the current rating – Part 3: Sections on operating conditions – Section 1: Reference operating conditions and selection of cable type*

IEC TR 62095, *Electric cables – Calculations for current ratings – Finite element method*

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