# IEC TR 60890

Edition 3.0 2022-09
REDLINE VERSION

# TECHNICAL REPORT

colour
inside

## A method of temperature-rise verification of low-voltage switchgear and controlgear assemblies by calculation

IEC TR 60890:2022-09 RLV(en)

**THIS PUBLICATION IS COPYRIGHT PROTECTED**
**Copyright © 2022 IEC, Geneva, Switzerland**

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

**About the IEC**
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

**About IEC publications**
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

**IEC publications search - webstore.iec.ch/advsearchform**
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

**IEC Just Published - webstore.iec.ch/justpublished**
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

**IEC Customer Service Centre - webstore.iec.ch/csc**
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

**IEC Products & Services Portal - products.iec.ch**
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

**Electropedia - www.electropedia.org**
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IECNORM.COM : Click to view the full PDF of IEC TR 60890:2022 RLV

# IEC TR 60890

Edition 3.0 2022-09
REDLINE VERSION

# TECHNICAL REPORT

colour
inside

## A method of temperature-rise verification of low-voltage switchgear and controlgear assemblies by calculation

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.130.20

ISBN 978-2-8322-5822-4

# CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

---

# A METHOD OF TEMPERATURE-RISE VERIFICATION OF LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES BY CALCULATION

## 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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

**This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TR 60890:2014. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.**

IEC TR 60890 has been prepared by subcommittee 121B: Low-voltage switchgear and controlgear assemblies, of IEC technical committee 121: Switchgear and controlgear and their assemblies for low-voltage. It is a Technical Report.

This third edition cancels and replaces the second edition published in 2014. This edition constitutes a technical revision.

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

- alignment with IEC 61439-1:2020;
- addition of individual annexes for guidance of technical explanations related to:
  - effect of an uneven power distribution;
  - additional temperature-rise due to solar radiation;
  - effect of different enclosure materials;
  - effect of different natural ventilation management;
  - forced ventilation management;
  - power losses calculation;
  - impact of an adjacent wall can have on the assembly cooling surface(s);
- maximum internal ambient temperature limit into an assembly;
- validity area of the calculation extended from 3 150 A to 3 200 A;
- addition of an algebraic equation to the different curves included in the document.

The text of this Technical Report is based on the following documents:

| Draft | Report on voting |
|---|---|
| 121B/136/DTR | 121B/147/RVDTR |

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

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

**IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.**

# INTRODUCTION

In the series of design verifications of IEC 61439-1 a temperature-rise verification of low-voltage power switchgear and controlgear assemblies ~~(hereafter called ASSEMBLIES)~~ is specified. This ~~may~~ can be by test, however, alternatives are acceptableunder defined circumstances. Selection of the method used for temperature-rise verification is the responsibility of the original manufacturer. Where applicable this document ~~may~~ can also be used for temperature-rise verification of similar products in accordance with other standards (e.g. IEC 60204-1). The method of calculation can also be used to determine the thermal power dissipation capability of an enclosure in accordance with IEC 62208 for a given internal air temperature-rise. The factors and coefficients, set out in this document have been derived from measurements on numerous assemblies and the method has been verified by comparison with test results.

# A METHOD OF TEMPERATURE-RISE VERIFICATION OF LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES BY CALCULATION

## 1 Scope

~~This Technical Report specifies a method of temperature-rise verification of low-voltage switchgear and controlgear assemblies by calculation.~~

~~The method is applicable to enclosed ASSEMBLIES or partitioned sections of ASSEMBLIES without forced ventilation. It is not applicable where temperature rise verification to the relevant product standard of the IEC 61439 series has been established~~

~~NOTE 1 The influence of the materials and wall thicknesses usually used for enclosures can have some effect on the steady state temperatures. However, the generalised approach used in this technical report ensures it is applicable to enclosures made of sheet steel, sheet aluminium, cast iron, insulating material and the like.~~

~~The proposed method is intended to determine the temperature-rise of the air inside the enclosure.~~

~~NOTE 2 The air temperature within the enclosure is equal to the ambient air temperature outside the enclosure plus the temperaturerise of the air inside the enclosure caused by the power losses of the installed equipment.~~

~~Unless otherwise specified, the ambient air temperature outside the ASSEMBLY is the air temperature indicated for the installation (average value over 24 h) of 35 °C. If the ambient air temperature outside the assembly at the place of use exceeds 35 °C, this higher temperatureis deemed to be the ambient air temperature.~~

This document specifies a method of air temperature-rise calculation inside enclosures for low-voltage switchgear and controlgear assemblies or similar products in accordance with their respective standard.

The method is primarily applicable to enclosed assemblies or partitioned sections of assemblies without forced ventilation. However, some technical guidance to adapt it for the use of forced ventilation is given in this document. The results obtained by using this method are directly influenced by the accuracy of the evaluation of power losses used as inputs to perform the thermal calculations.

NOTE The air temperature within the enclosure is equal to the ambient air temperature outside the enclosure plus the temperature-rise of the air inside the enclosure caused by the power losses of the installed equipment.

For the method to be applied, the maximum daily average ambient air temperature outside the assembly at the place of installation is specified between 10 °C and 50 °C. The maximum daily temperature does not exceed the maximum daily average temperature by more than 5 K.

Several annexes in this document provide guidance on how temperature-rise within assemblies can be affected by influences which are not considered in the calculation method included in this document, for example, when the assembly is subject to solar radiation. In such cases, different means of verification to that given in this document can be applied to ensure a definitive result and verification of the design.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 61439-1:2011, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*~~

IEC 61439 (all parts), *Low-voltage switchgear and controlgear assemblies*

IEEE C37.24-2017, *IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61439~~-1~~ (all parts) apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

## 4 Verification conditions ~~for application~~

~~This method of calculation is only applicable if the following conditions are fulfilled:~~

- ~~the power loss data for all built in components is available;~~
- ~~there is an approximately even distribution of power losses inside the enclosure;~~
- ~~the installed equipment is so arranged that air circulation is not significantly impeded;~~
- ~~the equipment installed is designed for direct current or alternating current up to and including 60 Hz with the total of supply currents not exceeding 3 150 A;~~
- ~~conductors carrying currents in excess of 200 A, and the adjacent structural parts are so arranged that eddy-current and hysteresis losses are minimised;~~
- ~~for enclosures with natural ventilation, the cross-section of the air outlet openings is at least 1,1 times the cross-section of the air inlet openings;~~
- ~~there are no more than three horizontal partitions in the ASSEMBLY or in a section of it;~~
- ~~where enclosures with external ventilation openings have compartments, the surface of the ventilation openings in each horizontal partition shall be at least 50 % of the horizontal cross-section of the compartment.~~

When this method of calculation is applied to low-voltage switchgear and controlgear assemblies the following conditions shall be fulfilled:

- the assembly is designed for AC currents and frequencies up to and including 1 600 A, 60 Hz. For higher current ratings or frequencies, the method could be used with additional verifications taking into account the effect of eddy-currents on the temperature distribution inside the assembly as required by the relevant product standards.

  NOTE 1 In IEC 61439-2, additional requirements for currents in excess of 1 600 A are specified to take into account the considerably increased power losses due to magnetic effects (eddy currents, proximity effect, skin effect)

- the assembly is designed for DC currents up to and including 3 200 A. For higher current ratings the method could be used with additional verifications as required by the relevant product standards;
- conductors carrying currents in excess of 200 A AC, and the adjacent structural parts are so arranged that eddy-current and hysteresis losses are negligible;
- there is an approximately even distribution of power losses inside the enclosure;

- the power losses data for all built-in components are available or can be calculated (see Clause 5);
- the installed equipment is so arranged that air circulation is not significantly impeded.

NOTE 2 When this method is used to determine the thermal power dissipation capability of an empty enclosure in accordance with IEC 62208, the above conditions do not apply.

# 5 Calculation method

## 5.1 Assumptions made in this calculation

To use the calculation method of this document, the following assumptions are deemed valid:

- the enclosure is made of metal (steel, aluminium, stainless steel) coated (both sides, inside and outside), insulating material like thermoplastic or thermoset or similar (see Annex D);
- the enclosure is made of a single layer material or multiple layers without air-gap;
- for enclosures with or without natural ventilation, there are no more than five horizontal partitions in the assembly or in a section of it;
- the enclosure is designed without ventilation openings or;
- the enclosure is designed with free air inlet and outlet ventilation openings, without the inclusion of any additional filter (see Annex E);
  - the cross-section of the air outlet openings is at least 10 % bigger than that of the inlet openings to permit the chimney effect;
  - the minimum cross section of air inlet openings is 10 cm$^2$;

  NOTE 1 Figure 3 and the formula given in Table 7 are not usable for lower cross sections. Assemblies with a sum of the air inlet openings less than 10 cm$^2$ are considered as assemblies without an air inlet.

  - if the enclosure has air inlet and outlet openings with filters for an IP5X rating or higher then these openings are not considered for the calculation;
  - for IP ratings lower than IP5X the effective free air cross section of the openings shall be used for calculation (see Annex E);
- where enclosures with natural ventilation openings have compartments, the surface of each horizontal partition shall be provided with free air ventilation openings of at least 50 % of the horizontal cross-section of the partition (see Clause B.1);
- power losses are considered as a sum of the followings:
  - power losses of low-voltage switchgear and controlgear (see Clause G.2);
  - power losses of conductors connecting low-voltage switchgear and controlgear (see Clause G.3);
  - power losses of busbars (see Clause G.4);
  - power losses of electronic devices (see Clause G.5);
- the enclosure is not subject to solar radiation.

## 5.2 Necessary information

The following data ~~is needed~~ shall be used to calculate the temperature-rise of the air inside an enclosure:

- dimensions of the enclosure: height/width/depth;
- type of installation of the enclosure according to Figure 4;
- design of enclosure, i.e. with or without ventilation openings;
- number of internal horizontal partitions;
- effective power loss of equipment installed in the enclosure, see Annex G;

– effective power loss ($P_v$) of conductors according to Annex I.

~~NOTE The effective power losses of the equipment installed in the circuits of the ASSEMBLY used for this calculation are the power losses at the rated currents of the various circuits.~~

## 5.3 Calculation procedure

### 5.3.1 General

For the enclosures specified in columns 4 and 5 of Table 1, the calculation of the temperature-rise of the air inside the enclosure is carried out using the formulae laid down in columns 1 to 3 of Table 1.

The pertinent factors and exponents (characteristics) are obtained from columns 6 to 10 of Table 1.

The symbols, units and designations are stated in Table 2.

For enclosures having more than one section with vertical partitions, the temperature-rise of the air inside the enclosure shall be determined separately for each section.

Where enclosures without vertical partitions or individual sections have an effective cooling surface greater than 11,5 m$^2$ or a width greater than about 1,5 m, they should be divided for the calculation into fictitious sections, whose dimensions approximate to the foregoing values.

NOTE The template (see Figure 9) can be used as a calculation aid.

### 5.3.2 Determination of the effective cooling surface $A_e$ of the enclosure

The calculation is carried out according to Formula (1) in column 1 of Table 1.

The effective cooling surface $A_e$ of an enclosure is the sum of the individual surfaces $A_o$ multiplied by the surface factor $b$. This factor takes into account the heat dissipation of the individual surfaces according to the type of installation of the enclosure (see Annex H for additional explanations).

### 5.3.3 Determination of the internal temperature-rise $\Delta t_{0,5}$ of the air at mid-height of the enclosure

The calculation is carried out according to Formula (2) in column 2 of Table 1.

In Formula (2) the enclosure constant $k$ allows for the size of the effective cooling surface for enclosures without ventilation openings and, in addition, for the cross-section of the air inlet openings for enclosures with ventilation openings.

The dependence of the temperature-rise occurring in the enclosure on the effective power loss $P$ is expressed by the exponent $x$.

The factor $d$ allows for the dependence of the temperature-rise on the number of internal horizontal partitions.

### 5.3.4 Determination of the internal temperature-rise $\Delta t_{1,0}$ of air at the top of the enclosure

The calculation is made according to Formula (3) in column 3 of Table 1.

Factor $c$ allows for the temperature distribution inside an enclosure. Its determination varies with the design and installation of the assembly as follows:

a) For enclosures without ventilation openings and with an effective cooling surface:

$$A_e > 1{,}25\ \text{m}^2$$

The factor $c$ from Figure 4, depends on the type of installation and the height/base factor $f$, where:

$$f = \frac{h^{1,35}}{A_b}$$

b) For enclosures with ventilation openings and with an effective cooling surface:

$$A_e > 1{,}25\ \text{m}^2$$

The factor $c$ from Figure 6, depends on the cross-section of air inlet openings and the height/base factor $f$, where:

$$f = \frac{h^{1,35}}{A_b}$$

c) For enclosures without ventilation openings and with an effective cooling surface:

$$A_e \leq 1{,}25\ \text{m}^2$$

The factor $c$ from Figure 8, depends on the height/width factor $g$, where:

$$g = \frac{h}{w}$$

where

$h$ is the enclosure height, in m;

$A_b$ is the surface area of the enclosure base, in m$^2$;

$w$ is the enclosure width, in m.

### 5.3.5 Characteristic curve for temperature-rise of air inside enclosure

#### 5.3.5.1 General

To evaluate the design according to Clause 7~~, it is necessary to apply~~, the calculated results of 5.3.3 and 5.3.4 shall be applied with the proper characteristic curve for temperature-rise of air inside the enclosure as a function of the enclosure height. The air temperatures within horizontal levels are practically constant.

#### 5.3.5.2 Temperature-rise characteristic curve for enclosures with an effective cooling surface $A_e$ exceeding 1,25 m$^2$

As a general rule, the characteristic curve of temperature-rise is adequately well defined by a straight line which runs through the points $\Delta t_{1,0}$ and $\Delta t_{0,5}$ (see Figure 1).

The internal air temperature-rise at the bottom of the enclosure is close to zero, i.e. the characteristic curve flattens out towards zero. In practice, the dotted part of the characteristic curve is of secondary importance.

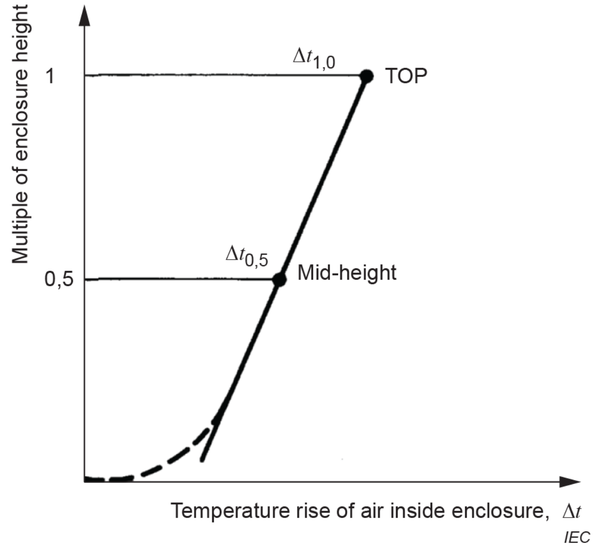


**Figure 1 – Temperature-rise characteristic curve for enclosures with $A_e$ exceeding 1,25 $m^2$**

### 5.3.5.3 Temperature-rise characteristic curve for enclosures with an effective cooling surface $A_e$ not exceeding 1,25 $m^2$

For this type of enclosure, the maximum temperature-rise in the upper quarter is constant and the values for $\Delta t_{1,0}$ and $\Delta t_{0,75}$ are identical (see Figure 2).

The characteristic curve is obtained by connecting the temperature-rise values at an enclosure level of 0,75 and 0,5 (see Figure 2).

The internal air temperature-rise at the bottom of the enclosure is close to zero, i.e. the characteristic curve flattens out towards zero. In practice, the dotted part of the characteristic curve is of secondary importance.

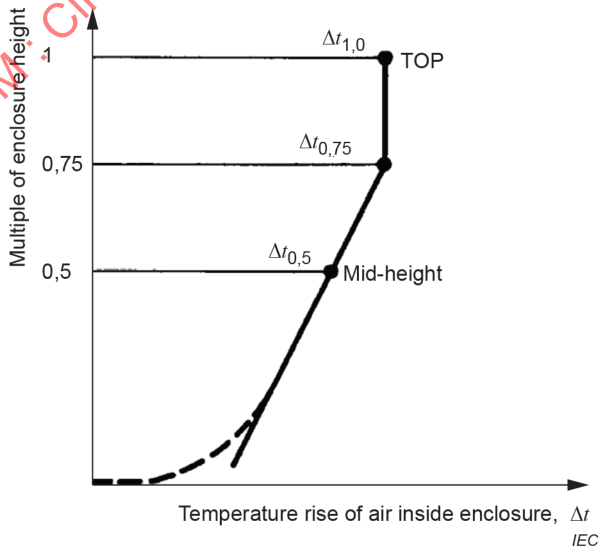


**Figure 2 – Temperature-rise characteristic curve for enclosures with $A_e$ not exceeding 1,25 $m^2$**

### 5.4 Maximum internal air temperature limits

This document contains a method to calculate the internal air temperature within an enclosure. The resulting temperature shall not exceed the maximum absolute temperature allowed by different types of devices and products installed inside.

The user of this document should refer to the manufacturer's instructions regarding the maximum operational temperature allowed for the devices used inside the assembly.

NOTE The value of internal air temperature has a direct influence on the ageing and operation of built-in components.

## 6 Further considerations

### 6.1 General

The means of temperature-rise calculation in this document relate to specific arrangements of assembly in the conditions as defined. These arrangements and conditions do not cover all designs of assembly or the conditions in which some are installed. Where good practises are applied the calculation methods in this document can lead to conservative results.

Annex B, Annex C, Annex D, Annex E, Annex F, Annex H, Annex J and Annex K detail good practice that can lead to an improvement in thermal performance or some aspects not considered in the calculation method in this document. However, when using these additional considerations, to ensure a defined performance of an assembly, further verification, e.g. test, shall be performed.

### 6.2 Guidance on the effects of an uneven power distribution

The aim of Annex B is to determine the temperature-rise where there is not an even power distribution within an assembly using as a starting point the temperature-rise of a reference design or calculation in accordance with Clause 5.

### 6.3 Guidance on the additional temperature-rise effect due to solar radiation

In case of outdoor assemblies that are subject to direct sunlight, solar irridiance can significantly increase internal air temperature-rise and require a derating of the rated currents of the assembly. See Annex C.

## 7 Evaluation of the design

It shall be determined whether the equipment within the assembly can operate satisfactorily at the relevant calculated internal air temperature-rise.

If it is not so, the parameters will have to be changed and the calculation repeated.

**Table 1 – Method of calculation, application, formulas and characteristics**

| 1 | 2 | 3 | 4 | 5 [a] | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Calculation formulae** | | | **Enclosure** | | **Characteristics** | | | | | **Characteristic curve** |
| **Effective cooling surface $A_e$** | **Temperature-rise of air** | | **Effective cooling surface $A_e$** | | **Factors** | | | | **Exponent** | **Plotting of temperature-rise characteristics** |
| | **At mid-height of the enclosure** | **At (internal) top of enclosure** | | | $b$ **see** | $k$ **see** | $d$ **see** | $c$ **see** | $x$ | |
| $A_e = \Sigma (A_o \times b)$ (1) | $\Delta t_{0,5} = k \times d \times P^x$ (2) | $\Delta t_{1,0} = c \times \Delta t_{0,5}$ (3) | >1,25 m$^2$ | Enclosure without ventilation openings | Table 3 | Figure 3 | Table 4 | Figure 4 | 0,804 | See 5.3.5.2 |
| | | | | Enclosure with ventilation openings | | Figure 5 | Table 5 | Figure 6 | 0,715 | |
| | | | ≤1,25 m$^2$ | Enclosure without ventilation openings | | Figure 7 | $d$=1 | Figure 8 | 0,804 | See 5.3.5.3 |

[a] For enclosure with ventilation openings with effective surface $A_e$ ≤ 1,25 m$^2$ the criteria of enclosures without ventilation openings can be used.

For symbols, units and designations, see Table 2.

For method of calculation, see also the examples given in Annex A.

**Table 2 – Symbols, units and designations**

| Symbol | Unit | Designation |
|---|---|---|
| $A_o$ | m$^2$ | Surfaces of external sides of enclosure |
| $A_b$ | m$^2$ | Enclosure base surface |
| $A_e$ | m$^2$ | Effective cooling surface of enclosure |
| $A_s$ | m$^2$ | Surface area, which can transport heat (usually excluding the bottom area) |
| α | W/m$^2$K | Heat transfer coefficient (includes conduction and radiation of heat) |
| $b$ | – | Surface factor |
| $c$ | – | Temperature distribution factor |
| $c_p$ | J/kg*K | Heat capacity (of air) |
| $d$ | – | Temperature-rise factor for internal horizontal partitions inside enclosure |
| $f$ | – | Height/base factor |
| $g$ | – | Height/width factor |
| $h$ | m | Enclosure height |
| $k$ | – | Enclosure constant |
| $n$ | – | Number of internal horizontal partitions (up to ~~three~~ five partitions) |
| $P$ | W | Effective power loss of equipment installed inside enclosure (determined according to Annex G) |
| $P_{890}$ | W | Calculated power dissipation of the enclosure according to this document, without considering natural ventilation |
| $P_{\text{fan}}$ | W | Power losses dissipated by forced ventilation |
| $P_v$ | W | Effective power losses of conductors |
| $P_w$ | W | Total dissipated power |
| ρ | kg/m$^3$ | Mass density (of air) at $T_a$ |
| $V$ | m$^3$/s | Volume flow rate of the air flow through the enclosure |
| $S_{\text{air}}$ | cm$^2$ | Cross-section of air inlet openings |
| $T_a$ | °C | Ambient temperature |
| $T_{\text{int}}$ | °C | Temperature inside the enclosure |
| $T_{\text{int,max}}$ | °C | Maximum temperature allowed inside the enclosure (limited e.g. by devices) |
| $w$ | m | Enclosure width |
| $x$ | – | Exponent |
| ~~$A_t$~~ $\Delta t$ | K | Temperature-rise of air inside enclosure in general |
| $\Delta t_{0,5}$ | K | Temperature-rise of air at (internal) mid-height of enclosure |
| $\Delta t_{0,75}$ | K | Temperature-rise of air at (internal) three quarters height of enclosure |
| $\Delta t_{1,0}$ | K | Temperature-rise of air at (internal) top of enclosure |

### Table 3 – Surface factor *b* according to the type of installation

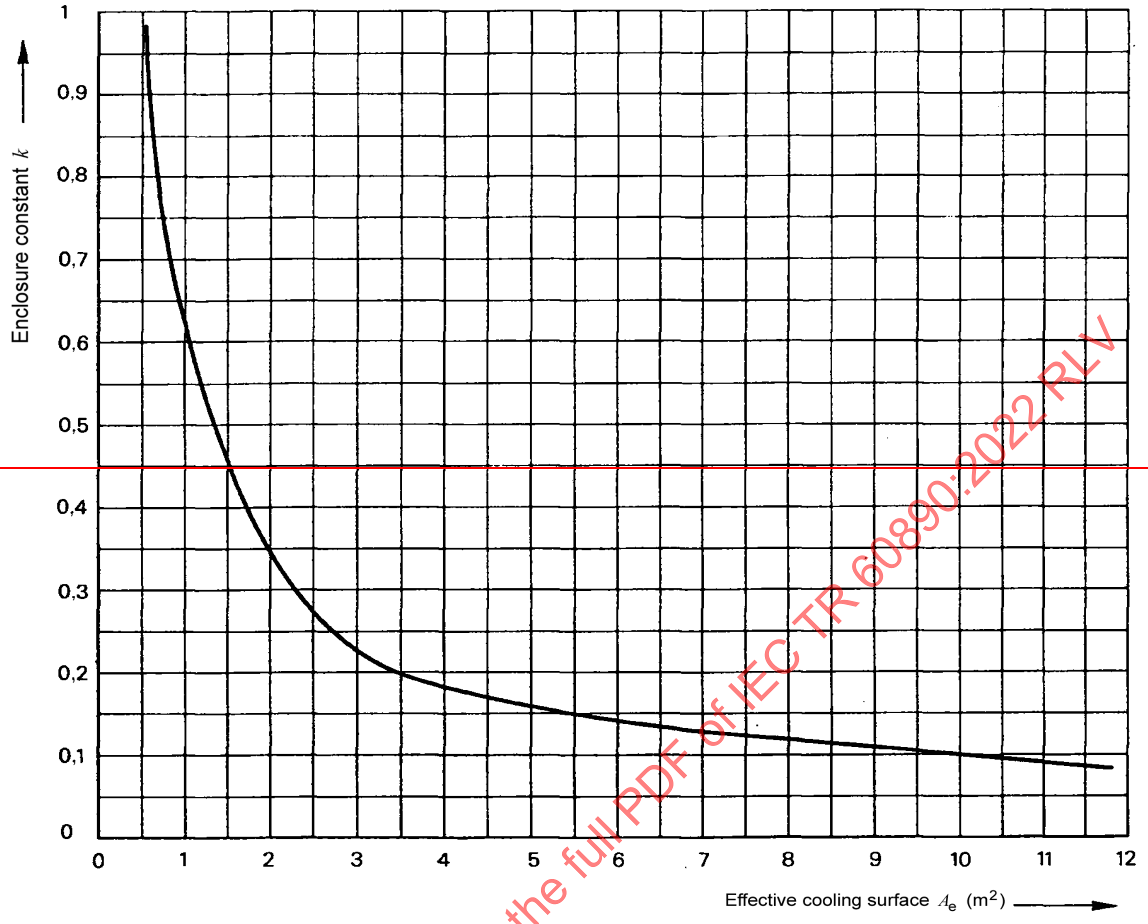
| **Type of installation** | **Surface factor**<br>***b*** |
|---|---|
| Exposed top surface | 1,4 |
| Covered top surface, e.g. of built-in enclosures | 0,7 |
| Exposed side faces, e.g. front, rear and side walls | 0,9 |
| Covered side faces, e.g. rear side of wall-mounted enclosures | 0,5 |
| Side faces of central enclosures | 0,5 |
| Floor surface | not taken into account |
| Fictitious side faces of sections (see 5.3) which have been introduced only for calculation purposes are not taken into account | |

### Table 4 – Factor *d* for enclosures without ventilation openings and with an effective cooling surface $A_e$ > 1,25 m$^2$

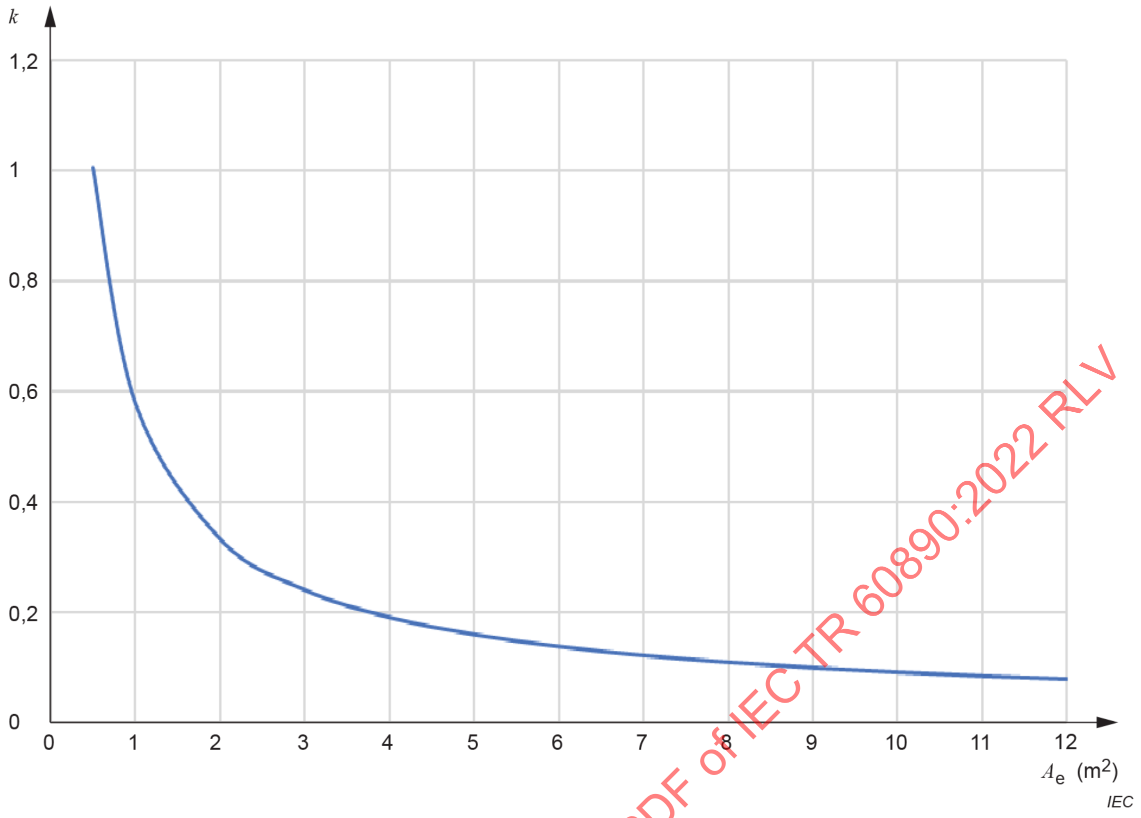
| **Number of horizontal partitions *n*** | **0** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| Factor *d* | 1,00 | 1,05 | 1,15 | 1,30 | 1,45 | 1,55 |
| NOTE Alternative factor *d* values than those of Table 4 can be used according to comparison with test results of similar configurations. | | | | | | |

### Table 5 – Factor *d* for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$

| **Number of horizontal partitions *n*** | **0** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| Factor *d* | 1,00 | 1,05 | 1,10 | 1,15 | 1,2 | 1,25 |
| NOTE Alternative factor *d* values than those of Table 5 can be used according to comparison with test results of similar configurations. | | | | | | |


Enclosure constant $k$
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Effective cooling surface $A_e$ (m$^2$)

IEC 1430/14



**Key**

$A_e$ effective cooling surface (see 5.3.2)

$k$ enclosure constant (see 5.3.3)

NOTE See Table 6 for the algebraic expression related to the curve.

Figure 3 – Enclosure constant $k$ for enclosures without ventilation openings, with an effective cooling surface $A_e > 1,25$ m$^2$

Boundary conditions: the factor $A_e$ shall be higher than 1,25 and not exceed 12.

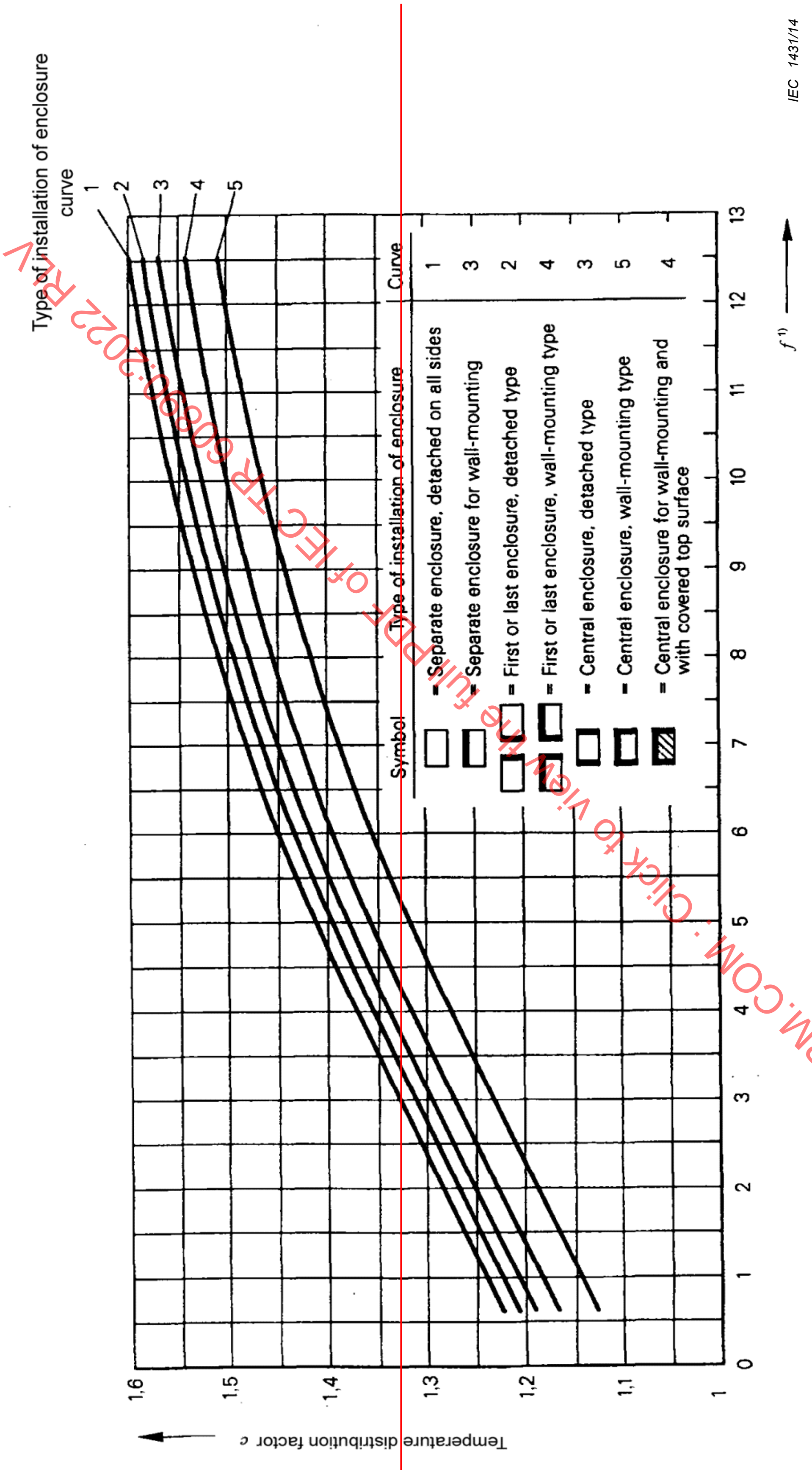
**Table 6 – Equation for Figure 3**

| Variable | Algebraic expression |
|---|---|
| $k$ | $k = 0,58 \times (A_e)^{-0,795}$ |

**Key**

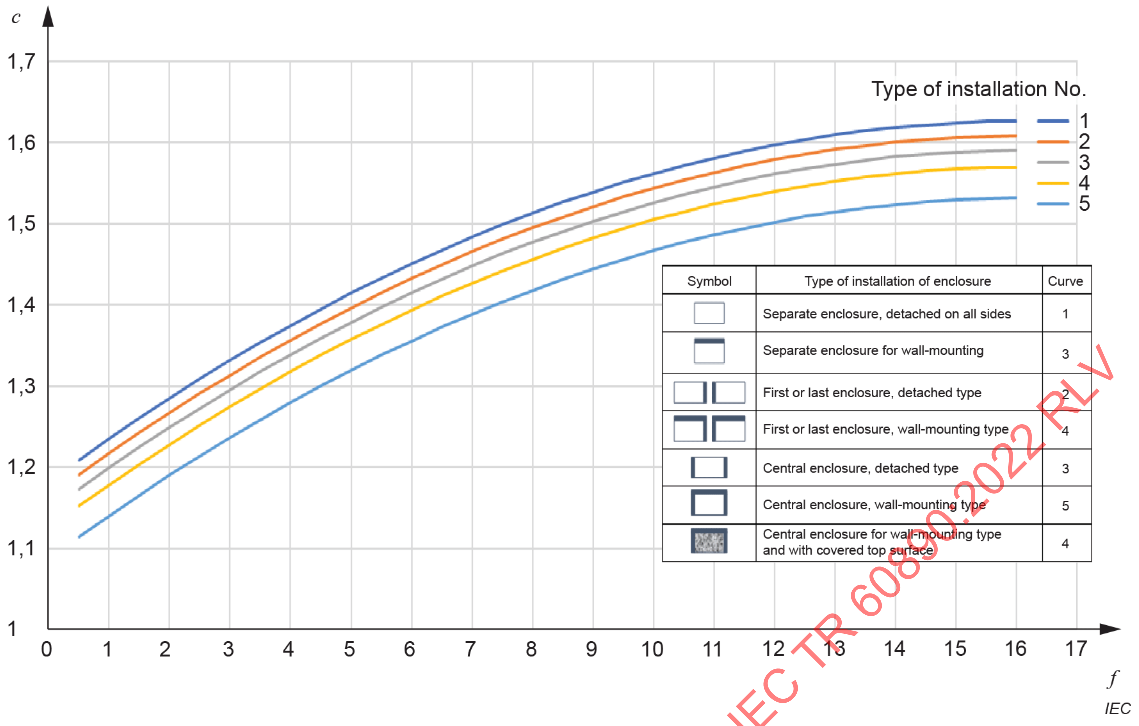
$A_e$ effective cooling surface (m$^2$)

$k$ enclosure constant



**Key**

~~1) Height/base factor, see 5.2.4.~~



| Symbol | Type of installation of enclosure | Curve |
|---|---|---|
| ☐ | Separate enclosure, detached on all sides | 1 |
| ☐ | Separate enclosure for wall-mounting | 3 |
| ☐ ☐ | First or last enclosure, detached type | 2 |
| ☐ ☐ | First or last enclosure, wall-mounting type | 4 |
| ☐ | Central enclosure, detached type | 3 |
| ☐ | Central enclosure, wall-mounting type | 5 |
| ▨ | Central enclosure for wall-mounting type and with covered top surface | 4 |

**Key**

*f* height/base factor (see 5.3.4)

*c* temperature distribution factor (see Figure 6 and Figure 8)

NOTE See Table 7 for the algebraic expressions related to the curves.

Boundary conditions: the factor *f* shall be higher than 0,3 and not exceed 16.

Figure 4 – Temperature distribution factor $c$ for enclosures without ventilation openings and with an effective cooling surface $A_e > 1{,}25\ \text{m}^2$

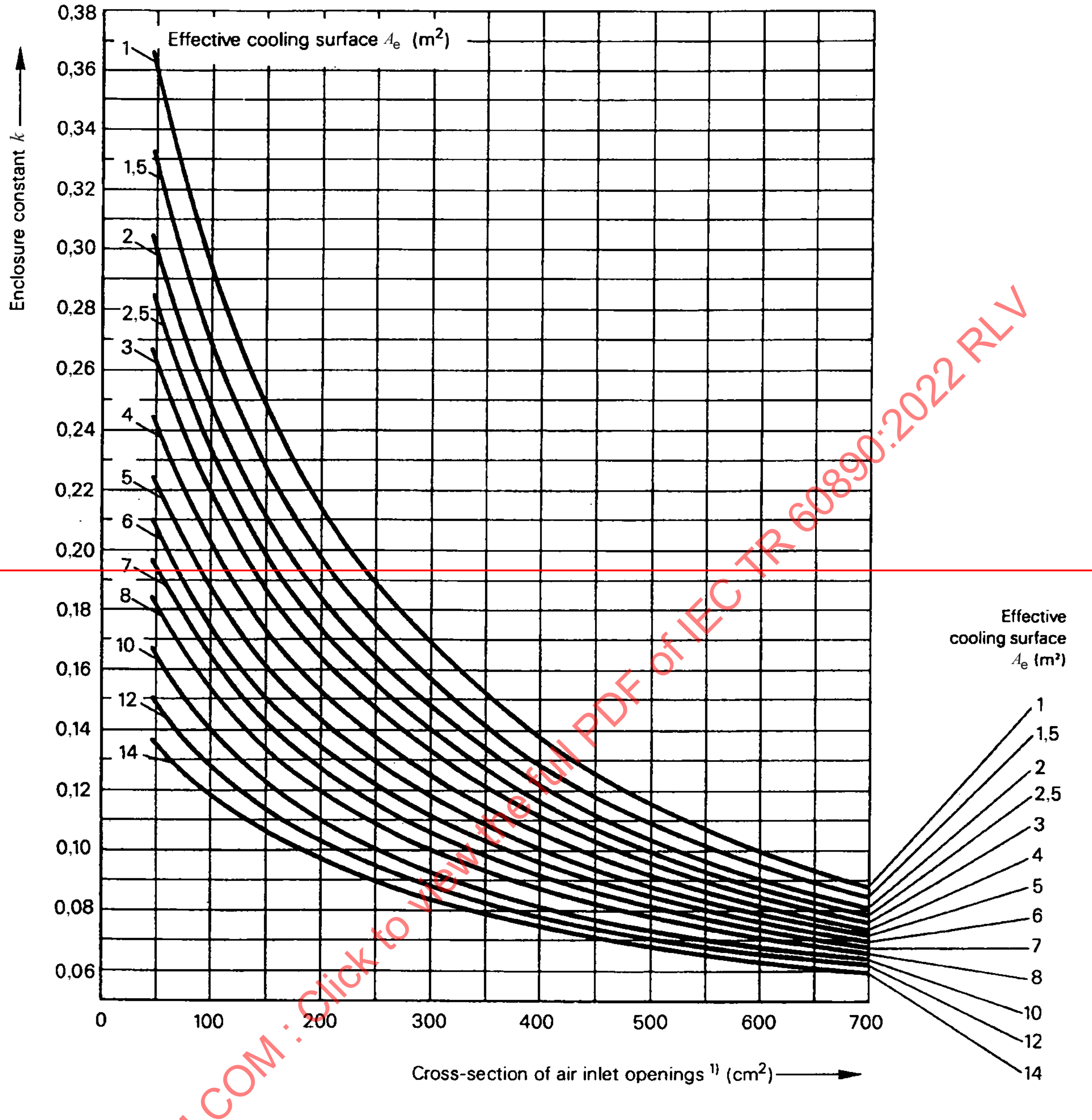
## Table 7 – Equations for Figure 4

| Installation type | Algebraic expressions |
|---|---|
| 5 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,087 |
| 4 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,125 |
| 3 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,146 |
| 2 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,164 |
| 1 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,182 |

**Key**

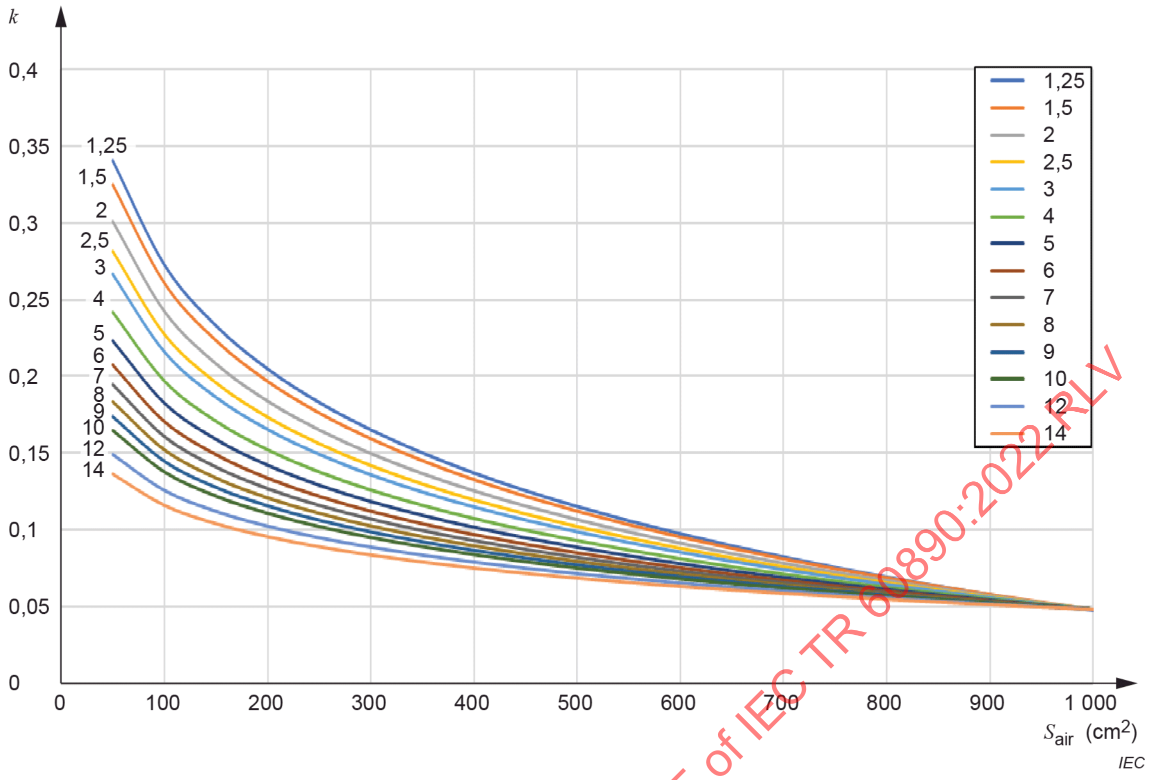
*c* temperature distribution factor

*f* height / base factor; $0{,}3 \leq f \leq 16$. If *f* exceeds 16 then *c* should be calculated with *f* equal 16.



~~**Key**~~

~~1) The cross-section of the corresponding air outlet openings should be at least 1,1 times that of the air inlet openings.~~



**Key**

$S_{air}$ cross-section of the corresponding air outlet openings

$k$ enclosure constant (see 5.3.3)

Boundary conditions: the factor $S_{air}$ shall be equal or higher than 10 cm$^2$ and not exceed 1 000 cm$^2$.

Figure 5 – Enclosure constant $k$ for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$

## Table 8 – Equations for Figure 5

| Variable | Algebraic expressions |
|---|---|
| A$k$ | A$k$ = 2,83 × $10^{-2}$ × ln($A_e$) – 10,39 × $10^{-2}$ |
| B$k$ | B$k$ = 19,52 × $10^{-2}$ × ln($A_e$) – 76,56 × $10^{-2}$ |
| $k$ | $k$ = A$k$ × ln ($S_{air}$) – B $k$ |

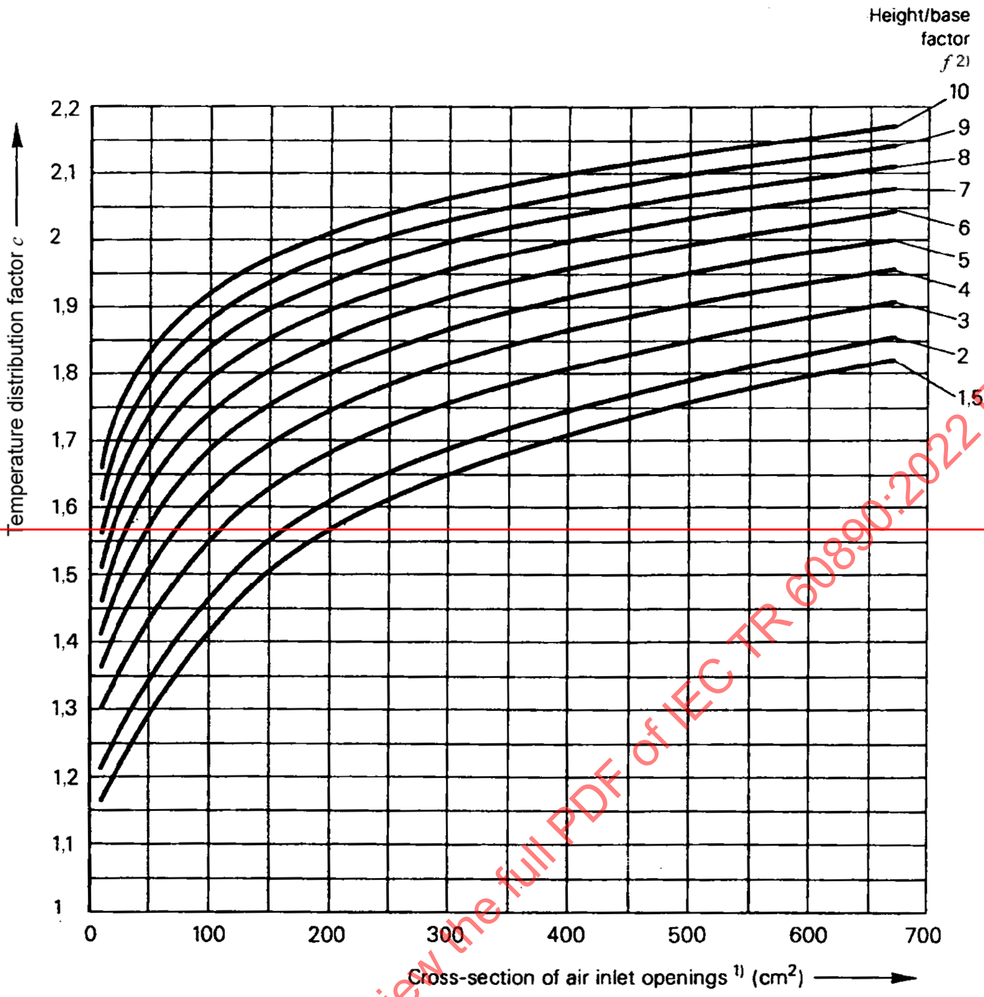
**Key**

$A_e$ effective cooling surface (m$^2$)

$S_{air}$ cross-section of air inlet openings (cm$^2$)

$k$ enclosure constant

A$k$ and B$k$ are intermediary variables to calculate the enclosure constant $k$.

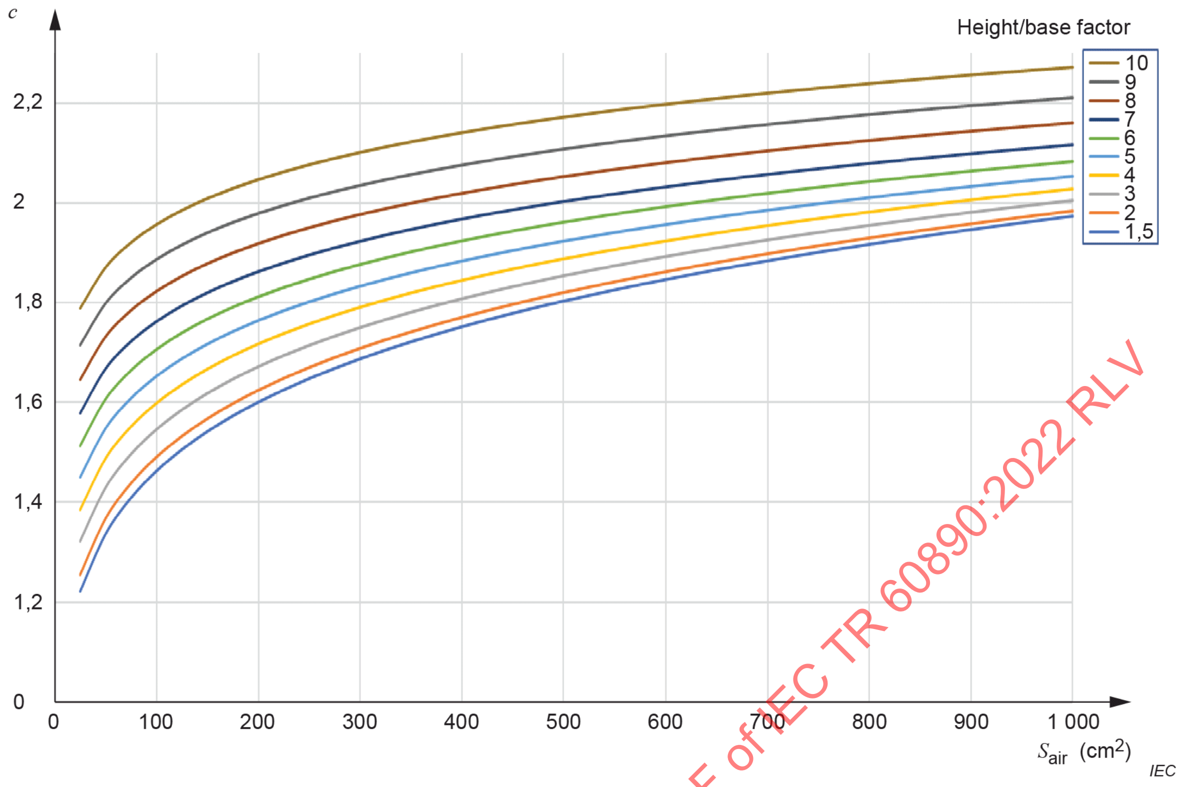


IEC 1433/14

~~**Key**~~

~~1) The cross-section of the corresponding air outlet openings should be at least 1,1 times that of the air inlet openings.~~

~~2) Height/base factor, see 5.2.4.~~



**Key**

$S_{air}$ cross-section of the corresponding air outlet openings, cross-section of the corresponding air outlet should be at least 1,1 times that of the air inlet openings

$c$ temperature distribution factor

NOTE 1 See Table 9 for the algebraic expressions related to the curves.

NOTE 2 Height/base factor $f$, see 5.3.4.

Boundary conditions: the factor $S_{air}$ shall be equal or higher than 10 cm$^2$ and not exceeding 1 000 cm$^2$.

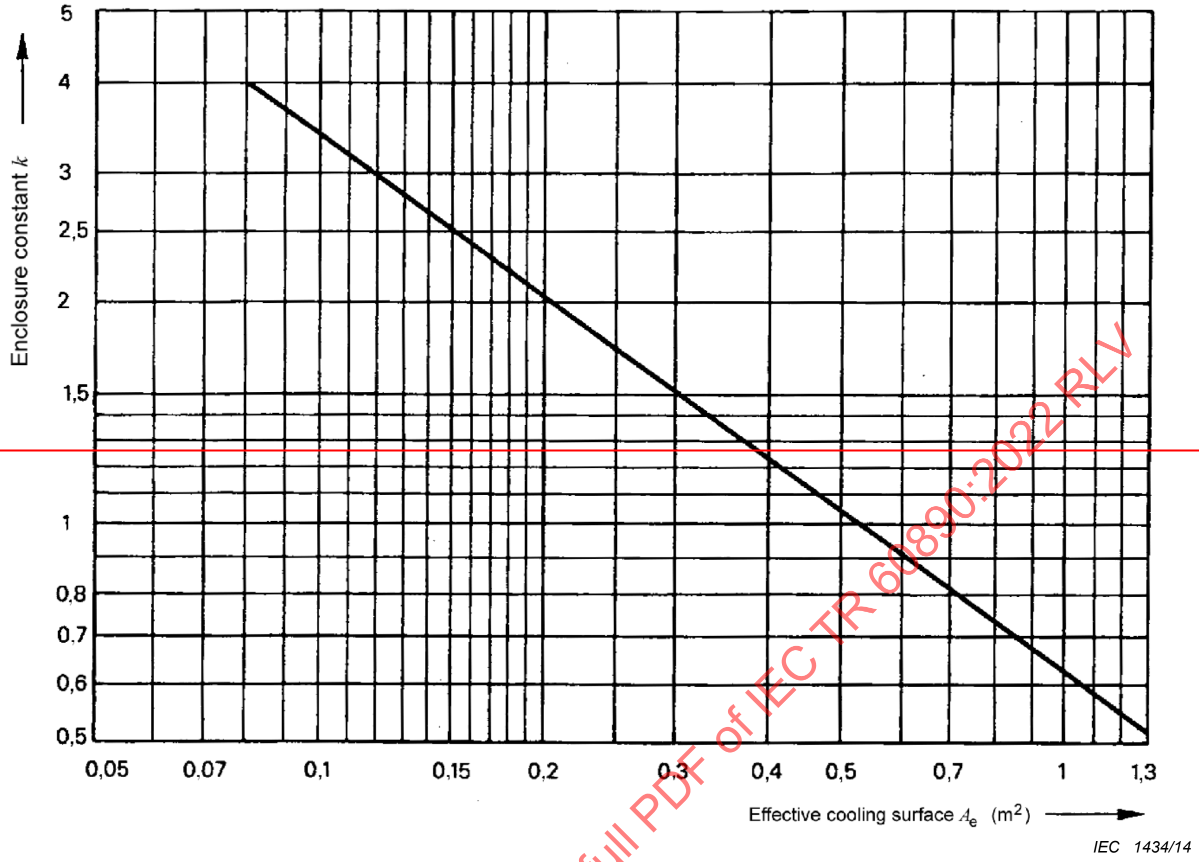
Figure 6 – Temperature distribution factor $c$ for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$

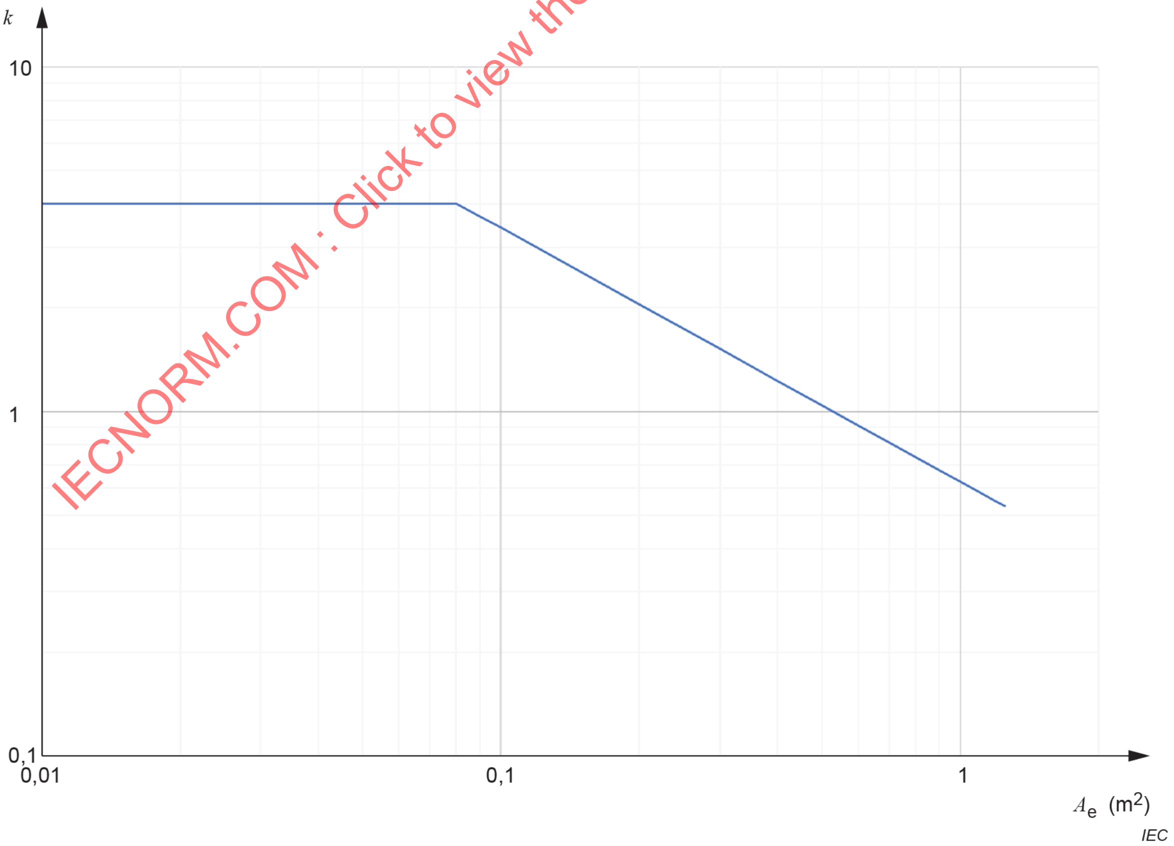
## Table 9 – Equations for Figure 6

| Variable | Algebraic expressions |
|---|---|
| $\mathrm{A}c$ | $\mathrm{A}c = 7{,}6 \times f + 69$ |
| $\mathrm{B}c$ | $\mathrm{B}c = 5{,}1 \times 10^{-4} \times f^{2} - 1{,}35 \times 10^{-2} \times f + 14{,}931 \times 10^{-2}$ |
| $c$ | $c = 0{,}01 \times \mathrm{A}c \times S_{\mathrm{air}} \wedge \mathrm{B}c$ |

**Key**

| | |
|---|---|
| $c$ | temperature distribution factor |
| $f$ | height / base factor |
| $S_{\mathrm{air}}$ | cross-section of air inlet opening ($\mathrm{cm}^2$) |
| $\mathrm{A}c$ and $\mathrm{B}c$ | are intermediary variables to calculate the temperature distribution factor $c$. |


Enclosure constant $k$
5
4
3
2,5
2
1,5
1
0,8
0,7
0,6
0,5
0,05
0,07
0,1
0,15
0,2
0,3
0,4
0,5
0,7
1
1,3
Effective cooling surface $A_e$ (m$^2$)
IEC 1434/14


$k$
10
1
0,1
0,01
0,1
1
$A_e$ (m$^2$)
IEC

**Key**

$A_e$ effective cooling surface (see 5.3.2)

$k$ enclosure constant (see 5.3.3)

NOTE See Table 10 for the algebraic expression related to the curve.

Boundary conditions: the factor $A_e$ shall not exceed 1,25.

**Figure 7 – Enclosure constant $k$ for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1,25$ m$^2$**

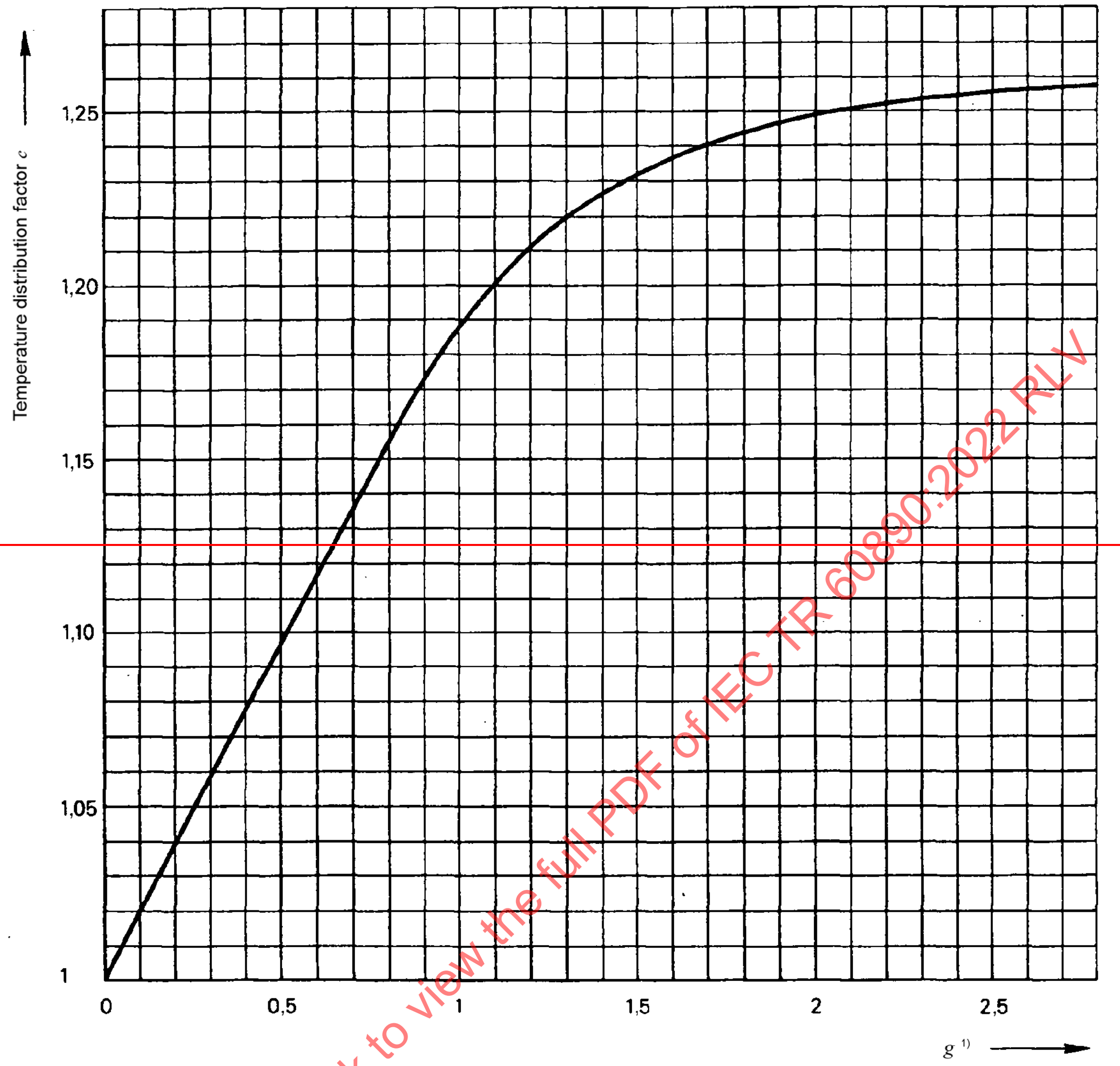
## Table 10 – Equation for Figure 7

| Variable | Algebraic expression |
|---|---|
| $k$ | $k = 4$ if ($A_e < 0{,}08$) else $0{,}626 \times (A_e)^{-0.737}$) |

**Key**

$A_e$ effective cooling surface (m$^2$)

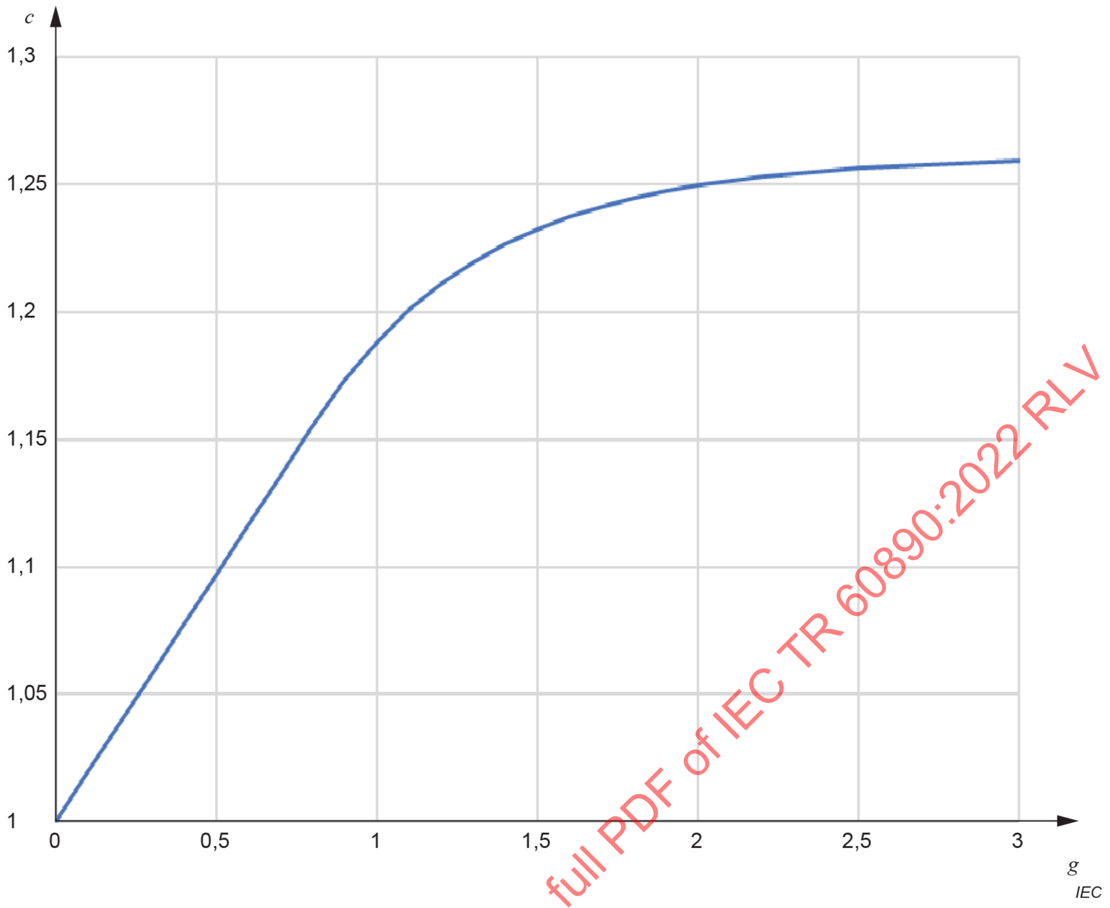
$k$ enclosure constant



IEC 1435/14

~~**Key**~~

~~1) Height/width factor, see 5.2.4.~~



**Key**

$g$ height/width factor (see 5.3.4)

$c$ temperature distribution factor

NOTE See Table 11 for the algebraic expressions related to the curve.

Boundary conditions: the factor $g$ shall be equal or higher than 0 and not exceed 3.

**Figure 8 – Temperature distribution factor $c$ for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1,25$ m$^2$**

## Table 11 – Equation for Figure 8

| Variable | Algebraic expressions |
|---|---|
| $c$ | If $g$ > 0,814 7, $c$ = 0,324 055 × (1- e(-1,882 7 × $g$ +0,385 79)) + 0,936 43<br>Else, $c$ = 0,193 54 × $g$ + 1 |

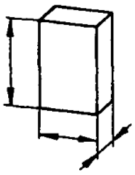
**Key**

$c$ temperature distribution factor

$g$ height / width factor

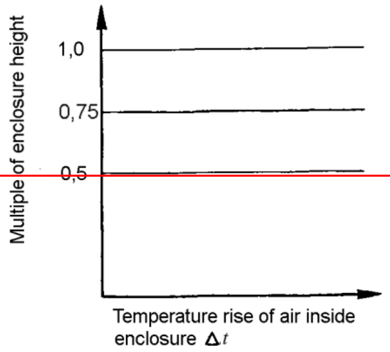
| |
|---|
| Calculation of temperature rise of air inside enclosures |

| | | | |
|---|---|---|---|
| Customer/plant | | | |
| Type of enclosure | | | |
| Relevant dimensions for temperature rise | height | mm | Type of installation: |
| | width | mm | Ventilation openings: yes/no |
| | depth | mm | Number of horizontal partitions: |

| Effective cooling surface |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m$^2$ | | m$^2$ |
| | | 2 | 3 | 4 | 5 |
| | Top | | | | |
| | Front | | | | |
| | Rear | | | | |
| | Left-hand side | | | | |
| | Right-hand side | | | | |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | |

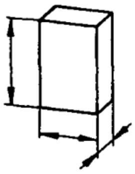
| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m$^2$ | Not exceeding 1,25 m$^2$ |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.2.4)<br>= ______________ = | $g = \frac{h}{w}$ (see 5.2.4)<br>= ______________ = |

| | | |
|---|---|---|
| Air inlet openings | cm$^2$ | |
| Enclosure constant $k$ | | |
| Factor for horizontal partitions $d$ | | |
| effective power loss $P$ | W | |
| $P^x = P^{\cdots}$ | | |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | |
| Temperature distribution factor $c$ | | |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | |

| | |
|---|---|
| Characteristic curve: |  IEC 1436/14 |

| Calculation of temperature-rise of air inside enclosure |
|---|

| | | | |
|---|---|---|---|
| Customer/plant | | | |
| Type of enclosure | | | |
| Relevant dimensions for temperature-rise | height | mm | Type of installation: |
| | width | mm | Ventilation openings: yes/no |
| | depth | mm | Number of horizontal partitions: |

| Effective cooling surface |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m$^2$ | | m$^2$ |
| | | 2 | 3 | 4 | 5 |
| | Top | | | | |
| | Front | | | | |
| | Rear | | | | |
| | Left-hand side | | | | |
| | Right-hand side | | | | |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m$^2$ | Not exceeding 1,25 m$^2$ |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4) | $g = \frac{h}{w}$ (see 5.3.4) |
| = ____________________ = | = ____________________ = |

| | | |
|---|---|---|
| Air inlet openings | cm$^2$ | |
| Enclosure constant $k$ | | |
| Factor for horizontal partitions $d$ | | |
| Effective power loss $P$ | W | |
| $P^x = P^{\cdots}$ | | |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | |
| Temperature distribution factor $c$ | | |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | |

Characteristic curve:

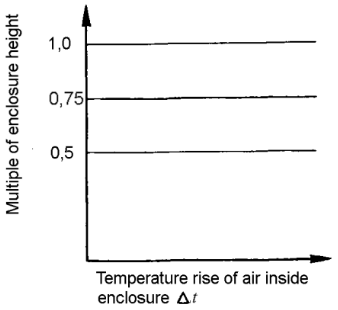


Figure 9 – Calculation of temperature-rise of air inside enclosures

# Annex A
(informative)

# Examples for the calculation of the temperature-rise of air inside enclosures

## A.1 Example 1

Single enclosure with exposed side faces without ventilation openings and without internal horizontal partitions (see Figure A.1).

Effective power loss of equipment installed in the enclosure: $P$ = 300 W.

Dimensions in millimetres

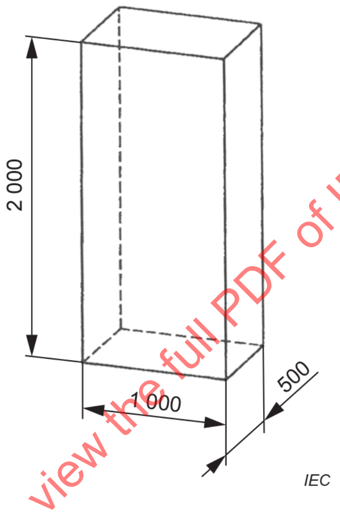


**Figure A.1 – Example 1, calculation for an enclosure with exposed side faces without ventilation openings and without internal horizontal partitions**

*Calculation*

(for ~~entries~~ values see template, Figure A.2 on Example 1):

- The effective cooling surface $A_e$ is determined according to 5.3.2.

  The individual surfaces are calculated from the enclosure dimensions, and the surface factor $b$ is taken from Table 3.
- The temperature-rise of air $\Delta t_{0,5}$ is determined according to 5.3.3.

  Formula (2) from column 2 of Table 1:

$$\Delta t_{0,5} = k \times d \times P^x \qquad \text{(A.1)}$$

Factor $k$ according to column 7 of Table 1 with $A_e$ > 1,25 m$^2$, as shown in Figure 3:

~~for $A_e$ = 6,64 m$^2$: $k$ = 0,135~~

for $A_e$ = 6,64 m$^2$: $k$ = 0,129

Factor $d$ according to column 8 of Table 1 with $A_e$ > 1,25 m$^2$, as specified in Table 4:

with number of horizontal partitions = 0: $d$ = 1,0

Effective power loss (as specified) $P$ = 300 W.

Exponent $x$ from column 10 of Table 1 with $A_e > 1,25$ m$^2$: $x$ = 0,804

With these values entered into the Formula (A.1), the following result is obtained:

~~$\Delta t_{0,5} = k \times d \times P^x = 0,135 \times 1,0 \times 300^{0,804}$~~

~~$\Delta t_{0,5} = 13,24 \text{ K} \approx 13,2 \text{ K}$~~

$$\Delta t_{0,5} = k \times d \times P^x = 0,129 \times 1,0 \times 300^{0,804}$$

$$\Delta t_{0,5} = 12,63 \text{ K} \approx 12,6 \text{ K}$$

- The temperature-rise of air $\Delta t_{1,0}$ is determined according to 5.3.4.

Formula (3) from column 3 of Table 1:

$$\Delta t_{1,0} = c \times \Delta t_{0,5} \quad \text{(A.2)}$$

Factor $c$ according to column 9 of Table 1 with $A_e > 1,25$ m$^2$, as shown in Figure 4:

$$f = \frac{h^{1,35}}{A_b} = \frac{2,2^{1,35}}{1,0 \times 0,5} = 5,80$$

Curve 1 of Figure 4 follows:

$$c = 1,44$$

With this value entered into Formula (A.2), the following result is obtained:

~~$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1,44 \times 13,24 = 19,07 \text{ K} \approx 19,1 \text{ K}$~~

$$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1,44 \times 12,63 = 18,18 \text{ K} \approx 18,2 \text{ K}$$

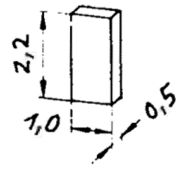
- The temperature-rise characteristic curve is determined for enclosures with $A_e > 1,25$ m$^2$, in accordance with 5.3.5.2 (see Figure A.2 in the template on Example 1).
- The evaluation of the design is made in accordance with Clause 7.

It ~~is to~~ shall be verified whether the equipment installed in the enclosure is capable of functioning satisfactorily at the specified currents and calculated temperature-rises, considering the ambient air temperature (see Note of Clause 1).

If this is not so, the parameters ~~will have to~~ shall be changed and the calculation repeated.

| Calculation of the temperature rise of air inside enclosures |
|---|

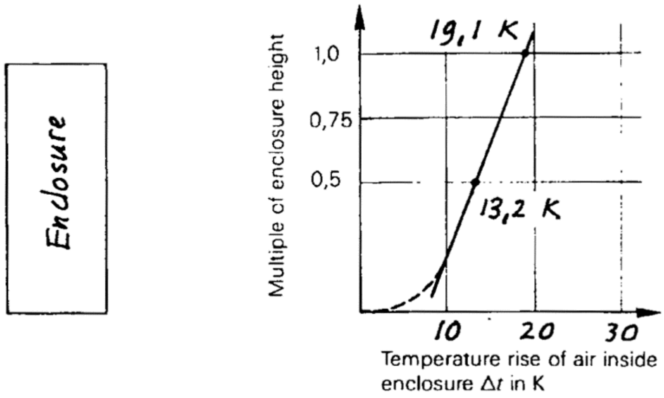
| | | | | |
|---|---|---|---|---|
| Customer/plant | Example 1 | | | |
| Type of enclosure | Single enclosure | | | |
| Relevant dimensions for temperature-rise | height | 2200 mm | Type of installation: | Detached on all sides |
| | width | 1000 mm | Ventilation openings: | ~~yes~~/no |
| | depth | 500 mm | Number of horizontal partitions: | 0 |

| | | Dimensions | $A_0$ | Surface factor $b$ according to Table 3 | $A_0 \times b$ (Column 3) × (Column 4) |
|---|---|---|---|---|---|
| Effective cooling surface |  | m × m | m² | | m² |
| | | 2 | 3 | 4 | 5 |
| | Top | 1,0 × 0,5 | 0,500 | 1,4 | 0,700 |
| | Front | 1,0 × 2,2 | 2,200 | 0,9 | 1,980 |
| | Rear | 1,0 × 2,2 | 2,200 | 0,9 | 1,980 |
| | Left-hand side | 0,5 × 2,2 | 1,100 | 0,9 | 0,990 |
| | Right-hand side | 0,5 × 2,2 | 1,100 | 0,9 | 0,990 |
| | $A_e = \Sigma(A_0 \times b)$ = Total | | | | 6,640 |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m² | Not exceeding 1,25 m² |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.2.4)<br>$= \frac{2,2^{1,35}}{1,0 \times 0,5} = 5,80$ | $g = \frac{h}{w}$ (see 5.2.4)<br>= ——— = |

| | | |
|---|---|---|
| Air inlet openings | cm² | 0 |
| Enclosure constant $k$ | | 0,135 |
| Factor for horizontal partitions $d$ | | 1,0 |
| Effective power loss $P$ | W | 300 |
| $P^x = P^{0,804}$ | | 98,09 |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | 13,24 ≈ 13,2 K |
| Temperature distribution factor $c$ | | 1,44 |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | 19,07 ≈ 19,1 K |

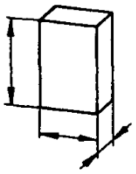
Characteristic curve:



IEC 1438/14

| Calculation of temperature-rise of air inside enclosure |
|---|

| | | | | |
|---|---|---|---|---|
| Customer/plant **Example 1** | | | | |
| Type of enclosure **Single enclosure** | | | | |
| Relevant dimensions for temperature-rise | Height | **2 200** | mm | Type of installation: **Detached on all sides** |
| | Width | **1 000** | mm | Ventilation openings: ~~**yes**~~**/no** |
| | Depth | **500** | mm | Number of horizontal partitions: **0** |

| Effective cooling surface |  | Dimensions<br>m × m | $A_o$<br>m² | Surface factor $b$ according to Table 3 | $A_o \times b$<br>(column 3) × (column 4)<br>m² |
|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 |
| | Top | **1,0 × 0,5** | **0,5** | **1,4** | **0,7** |
| | Front | **1,0 × 2,2** | **2,2** | **0,9** | **1,98** |
| | Rear | **1,0 × 2,2** | **2,2** | **0,9** | **1,98** |
| | Left-hand side | **0,5 × 2,2** | **1,1** | **0,9** | **0,99** |
| | Right-hand side | **0,5 × 2,2** | **1,1** | **0,9** | **0,99** |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | **6,64** |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m² | Not exceeding 1,25 m² |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4) | $g = \frac{h}{w}$ (see 5.3.4) |
| = $\frac{\mathbf{2,2^{1,35}}}{\mathbf{1 \times 0,5}}$ = **5,8** | = $\frac{\quad}{\quad}$ = |

| | | |
|---|---|---|
| Air inlet openings | cm² | **0** |
| Enclosure constant $k$ | | **0,129** |
| Factor for horizontal partitions $d$ | | **1** |
| Effective power loss $P$ | W | **300** |
| $P^x = P^{\cdots}$ | | **98,09** |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | **12,63 K ≈ 12,6 K** |
| Temperature distribution factor $c$ | | **1,44** |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | **18,18 K ≈ 18,2 K** |

Characteristic curve:

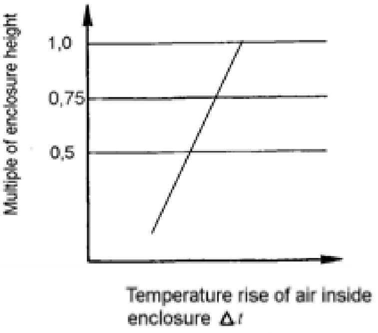


**Figure A.2 – Example 1, calculation for a single enclosure**

## A.2 Example 2

Enclosure for wall-mounting with ventilation openings

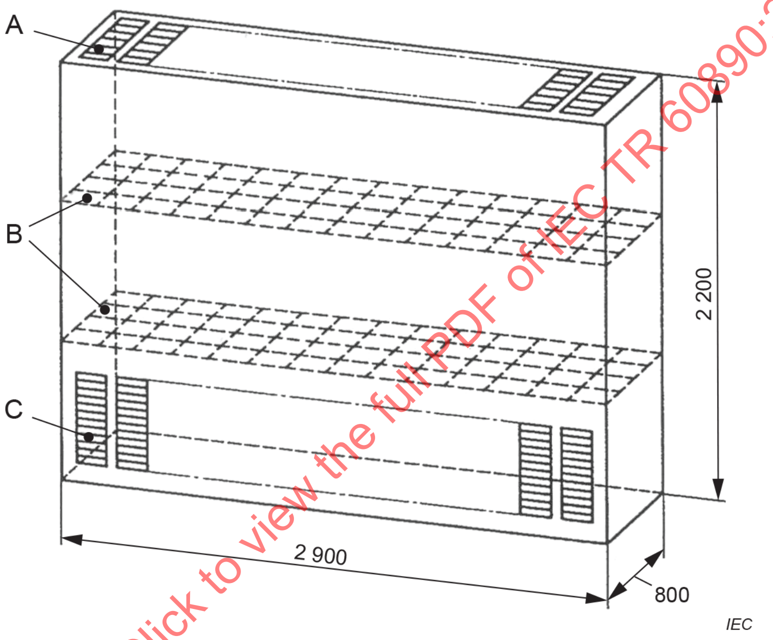
cross-section of air inlet openings = 1 220 cm$^2$

cross-section of air outlet openings = 1 800 cm$^2$

with two horizontal partitions inside the enclosure. Each horizontal partition, for example perforated plate, has ventilation openings, the cross-sectional areas of which exceed 50 % of the enclosure cross-section (see Figure A.3 and Figure A.4).

Effective power loss of equipment installed in the enclosure $P$ = 2 200 W.

Dimensions in millimetres



**Key**

A Air outlet openings

B Horizontal partitions with ventilation openings, for example perforated plate

C Air inlet openings

**Figure A.3 – Example 2, calculation for an enclosure for wall-mounting with ventilation openings**

Calculation

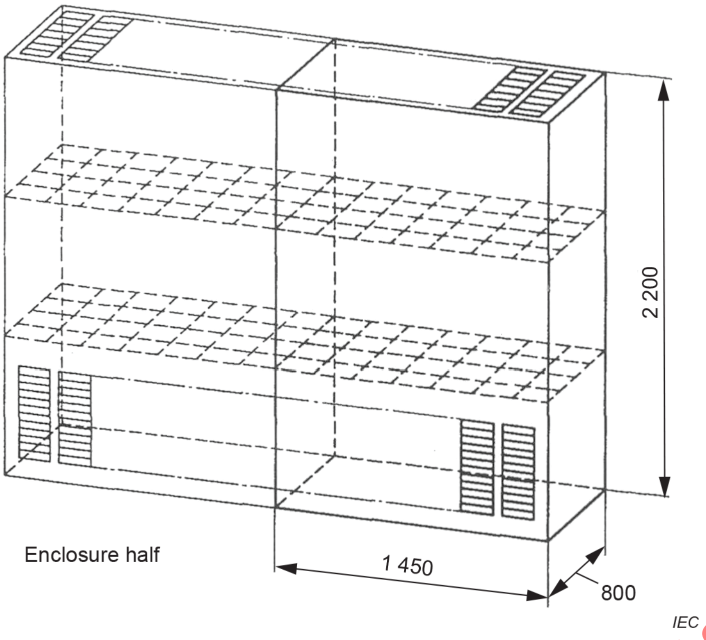
(for ~~entries~~ values see template Figure A.5 on Example 2):

Given an expected cooling surface of the enclosure is more than 11,5 m$^2$ and has an enclosure width exceeding 1,5 m, the entire enclosure ~~is to~~ shall be divided, for calculation purposes, into sections (partial enclosures) as indicated in 5.3.1. To simplify the procedure, as no structural divisions are available, the entire enclosure is, in this example, divided into two equal sections (enclosure halves). The power losses and ventilation openings are supposed to be evenly distributed in both parts (enclosure halves) so that for the calculation they are divided by two.

The calculation is carried out for only one enclosure half, the result being applicable to the other half.

- Necessary information according to 5.2 for one half of the enclosure

Dimensions in millimetres



Enclosure for wall-mounting with air inlet openings

$$= \frac{1\,220}{2} = 610\ \text{cm}^2$$

With air outlet openings

$$= \frac{1\,800}{2} = 900\ \text{cm}^2$$

With two horizontal partitions, for example perforated plate

Effective power loss

$$= \frac{2\,200}{2} = 1\,100\ \text{W}$$

**Figure A.4 – Example 2, calculation for one enclosure half**

- The effective cooling surface of each enclosure half is determined according to 5.3.2.

  The individual surfaces are calculated from the enclosure dimensions, and the surface factor $b$ is taken from Table 3.

  The dividing surface between the two enclosure halves which has been obtained as a result of the fictitious division, is not taken into account in accordance with Table 3.

- The temperature-rise of air $\Delta t_{0,5}$ is determined according to 5.3.3.

  Formula (2) from column 2 of Table 1

$$\Delta t_{0,5} = k \times d \times P^x \qquad \text{(A.3)}$$

Factor $k$ according to column 7 of Table 1 and $A_e$ > 1,25 m$^2$, as shown in Figure 5.

For 610 cm$^2$ air inlet openings and $A_e$ = 7,674 m$^2$: $k$ = 0,071 3

Factor $d$ according to column 8 of Table 1 and $A_e$ > 1,25 m$^2$ as specified in Table 5 with two horizontal partitions: $d$ = 1,10

Effective power loss (as specified) $P$ = 1 100 W

Exponent $x$ from column 10 of Table 1 with $A_e$ > 1,25 m$^2$: $x$ = 0,715

With these values entered into the above Formula (A.3), the following result is obtained:

~~$\Delta t_{0,5} = k \times d \times P^x = 0{,}071 \times 1{,}0 \times 1\,100^{0{,}715}$~~

~~$\Delta t_{0,5} = 11{,}67\ \text{K} \approx 11{,}7\ \text{K}$~~

$$\Delta t_{0,5} = k \times d \times P^x = 0{,}071 \times 1{,}10 \times 1\,100^{0{,}715}$$

$$\Delta t_{0,5} = 11{,}72\ \text{K} \approx 11{,}7\ \text{K}$$

- The temperature-rise of air $\Delta t_{1,0}$ is determined according to 5.3.4.

  Formula (3) from column 3 of Table 1

$$\Delta t_{1,0} = c \times \Delta t_{0,5} \tag{A.4}$$

Factor $c$ according to column 9 of Table 1 and $A_e$ > 1,25 $m^2$, as shown in Figure 6.

$$f = \frac{h^{1,35}}{A_b} = \frac{2{,}2^{1,35}}{1{,}45 \times 0{,}8} = 2{,}50$$

Figure 6 shows that, for 610 $cm^2$ air inlet openings:

~~$c = 1{,}87$~~

$$c = 1{,}88$$

With these values entered into Formula (A.4), the following result is obtained:

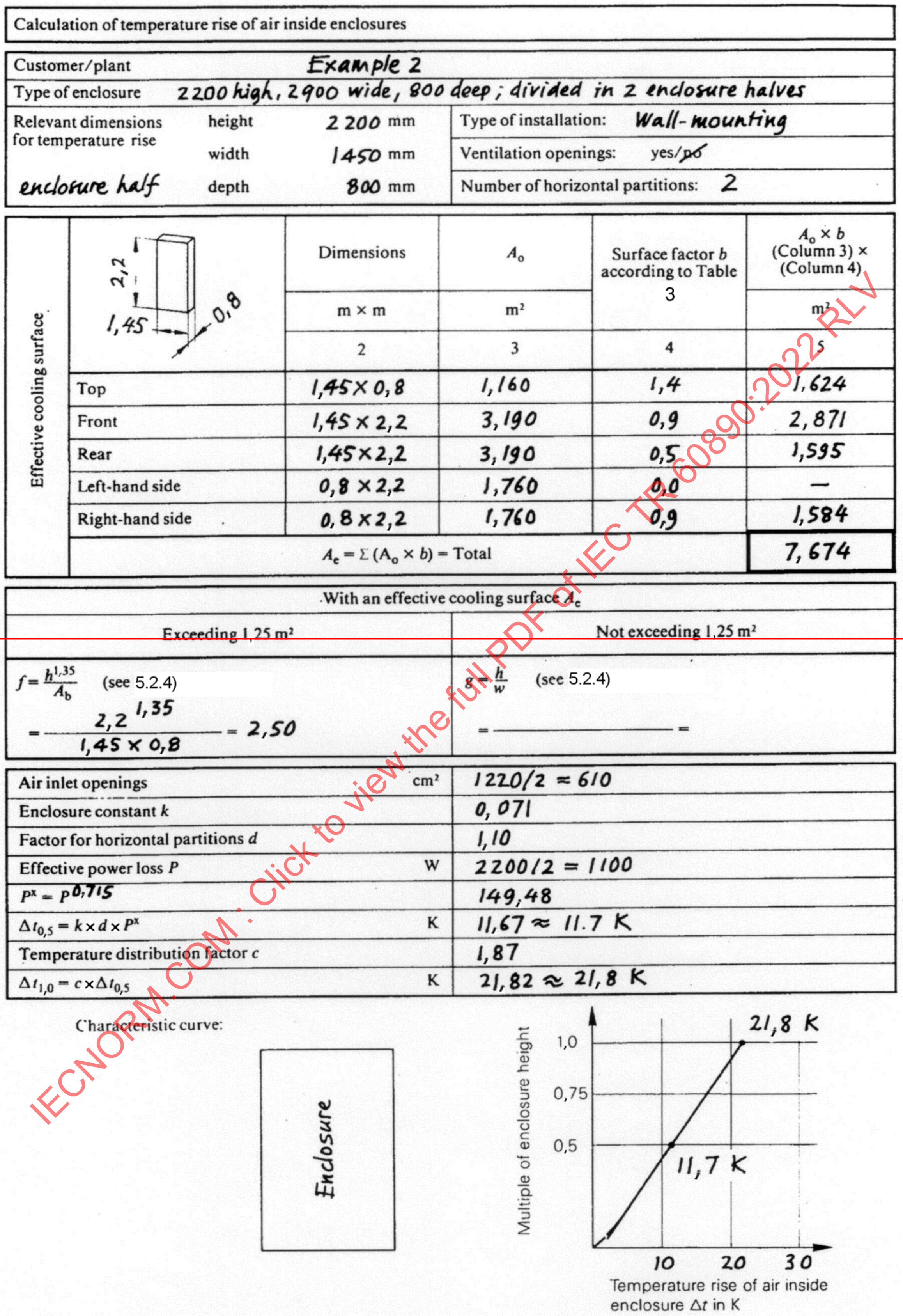
~~$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1{,}87 \times 11{,}67 = 21{,}82\ \text{K} \approx 21{,}8\ \text{K}$~~

$$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1{,}87 \times 11{,}67 = 22{,}03\ \text{K} \approx 22\ \text{K}$$

- The temperature-rise characteristic curve is determined for enclosures with $A_e$ > 1,25 $m^2$, in accordance with 5.3.5.2 (see Figure A.5 in the template on Example 2).
- The evaluation of the design is made in accordance with Clause 7.

  It ~~is to~~ shall be verified whether the equipment installed in the enclosure is capable of functioning satisfactorily at the specified currents and calculated temperature-rises, considering the ambient air temperature (see Note of Clause 1).

  If this is not so, the parameters ~~will have to~~ shall be changed and the calculation repeated.



| Calculation of temperature rise of air inside enclosures | | | |
|---|---|---|---|
| Customer/plant | Example 2 | | |
| Type of enclosure | 2200 high, 2900 wide, 800 deep; divided in 2 enclosure halves | | |
| Relevant dimensions for temperature rise<br>enclosure half | height 2 200 mm<br>width 1450 mm<br>depth 800 mm | Type of installation: Wall-mounting<br>Ventilation openings: yes/~~no~~<br>Number of horizontal partitions: 2 | |

| Effective cooling surface | | Dimensions | $A_0$ | Surface factor $b$ according to Table 3 | $A_0 \times b$ (Column 3) × (Column 4) |
|---|---|---|---|---|---|
| | | m × m | m² | | m² |
| | | 2 | 3 | 4 | 5 |
| | Top | 1,45 × 0,8 | 1,160 | 1,4 | 1,624 |
| | Front | 1,45 × 2,2 | 3,190 | 0,9 | 2,871 |
| | Rear | 1,45 × 2,2 | 3,190 | 0,5 | 1,595 |
| | Left-hand side | 0,8 × 2,2 | 1,760 | 0,0 | — |
| | Right-hand side | 0,8 × 2,2 | 1,760 | 0,9 | 1,584 |
| | $A_e = \Sigma (A_0 \times b)$ = Total | | | | 7,674 |

With an effective cooling surface $A_e$

| Exceeding 1,25 m² | Not exceeding 1,25 m² |
|---|---|
| $f = \frac{h^{1,35}}{A_b}$ (see 5.2.4)<br>$= \frac{2,2^{1,35}}{1,45 \times 0,8} = 2,50$ | $g = \frac{h}{w}$ (see 5.2.4)<br>$= \text{\_\_\_\_\_\_} =$ |

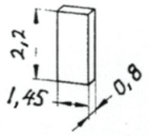
| | | |
|---|---|---|
| Air inlet openings | cm² | 1220/2 = 610 |
| Enclosure constant $k$ | | 0,071 |
| Factor for horizontal partitions $d$ | | 1,10 |
| Effective power loss $P$ | W | 2200/2 = 1100 |
| $P^x = P^{0,715}$ | | 149,48 |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | 11,67 ≈ 11.7 K |
| Temperature distribution factor $c$ | | 1,87 |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | 21,82 ≈ 21,8 K |

Characteristic curve:

IEC 1441/14

Calculation of temperature-rise of air inside enclosure

| | | | | |
|---|---|---|---|---|
| Customer/plant **Example 2** | | | | |
| Type of enclosure **2 200 high, 2 900 wide, 800 deep; divided in 2 enclosure halves** | | | | |
| Relevant dimensions for temperature-rise | Height | **2 200** | mm | Type of installation: **Wall-mounting** |
| | Width | **1 450** | mm | Ventilation openings: **yes/~~no~~** |
| | Depth | **800** | mm | Number of horizontal partitions: **0** |

| Effective cooling surface |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m² | | m² |
| | | 2 | 3 | 4 | 5 |
| | Top | **1,45 × 0,8** | **1,16** | **1,4** | **1,624** |
| | Front | **1,45 × 2,2** | **3,19** | **0,9** | **2,871** |
| | Rear | **1,45 × 2,2** | **3,19** | **0,5** | **1,595** |
| | Left-hand side | **0,8 × 2,2** | **1,76** | **0,0** | **–** |
| | Right-hand side | **0,8 × 2,2** | **1,76** | **0,9** | **1,584** |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | **7,674** |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m² | Not exceeding 1,25 m² |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4) | $g = \frac{h}{w}$ (see 5.3.4) |
| = $\frac{\mathbf{2,2^{1,35}}}{\mathbf{1,45 \times 0,8}}$ = **2,5** | = $\frac{\quad}{\quad}$ = |

| | | |
|---|---|---|
| Air inlet openings | cm² | **610** |
| Enclosure constant $k$ | | **0,071 3** |
| Factor for horizontal partitions $d$ | | **1,1** |
| Effective power loss $P$ | W | **2 200/2 = 1 100** |
| $P^x = P^{\cdots}$ | | **149,48** |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | **11,72 K ≈ 11,7 K** |
| Temperature distribution factor $c$ | | **1,88** |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | **22,03 K ≈ 22 K** |

Characteristic curve:

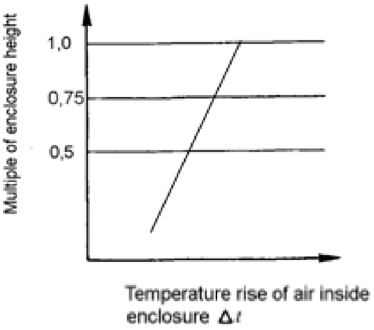


Figure A.5 – Example 2, calculation for an enclosure for wall-mounting with ventilation openings

# Annex B
(informative)

## Guidance on the effects of an uneven power distribution

### B.1 Horizontal partition

For typical assemblies used in the distribution of electrical energy, functional units are installed one above another with horizontal partitions in between each of the functional units. Typical arrangements are shown in the examples of Figure B.1

**a) Assembly without ventilation openings, and less than 50 % perforation in horizontal partition**

**b) Assembly with ventilation openings, and at least 50 % perforation in horizontal partition**

**Key**

| | |
|---|---|
| 1 to 5 | horizontal separation |

**Figure B.1 – Examples of assemblies with horizontal partitions**

The calculation method in Clause 5 assumes:

1) there is an approximately even power distribution within the assembly; and,
2) with a ventilated assembly, the area of the ventilation openings (perforation) in each horizontal partition is at least 50 % of the horizontal cross-section of the compartment to ensure a sufficient air flow through the compartment.

In some assemblies, for example certain designs of motor control centre (MCC), these conditions are not fulfilled; uneven power distribution can result from one circuit having a much higher power dissipation per unit volume (circuit with highest power dissipation) than the others and/or the perforation in horizontal partitions can be much less than 50 % of the horizontal cross section of the compartment.

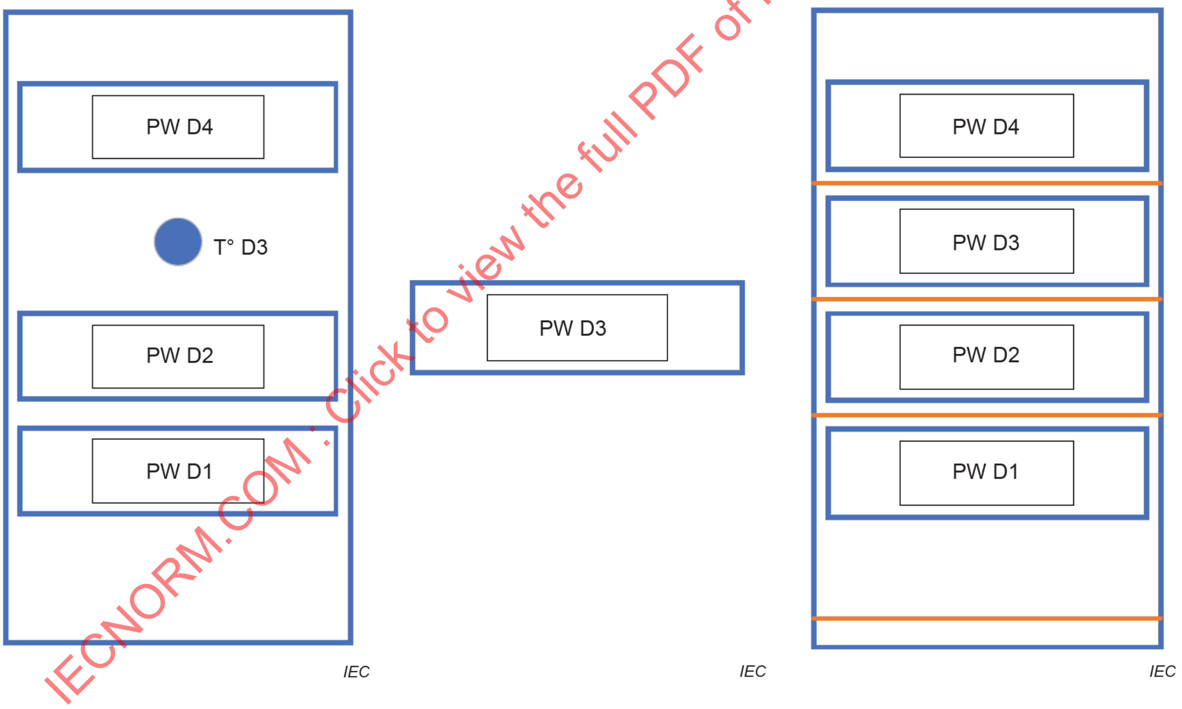
### B.2 Calculation of internal air temperature-rise for assemblies with ventilation openings with even power distribution and less than 50 % perforation in horizontal partitions

Assuming the power dissipation is approximately even within the section being considered, calculate the temperature-rise assuming there is no ventilation. The air temperature at any position within the section shall not exceed the maximum operating temperature allowed for the components at their respective positions within the section. See 5.4.

## B.3 Calculation of internal air temperature-rise with an uneven power distribution

This is a two or three step process.

- First step: determine the air temperature-rise at the point in the section where the higher-power dissipation circuit shall be located. This can be by measurement of the temperature in a reference design temperature-rise test. Alternatively, using this document calculate the air temperature-rise at the point in the section where the higher-power circuit shall be located considering the total power loss of the section, excluding the power loss of the higher-power circuit. For example, T° D3 in Figure B.2.
- Second step: assume the higher-power circuit (PW D3 in Figure B.2) is enclosed as it is within the assembly by using factors for covered surfaces in Table 3, and calculate the air temperature within PW D3 in accordance with 5.3, using the dimensions of PW D3 and assuming an ambient temperature T° D3. The calculated air temperature within PW D3 shall not exceed the maximum operating temperature allowed for the components installed within PW D3. See 5.4.
- Third step: if the higher-power circuit is located at the top position, this step is not required. If the higher-power circuit is not located at the top of its section using 5.3, calculate the air temperature within the section considering the total power loss within the section. The calculated air temperature at any position within the section shall not exceed the maximum operating temperature allowed for the components at their respective positions. See 5.4.



**Step 1: calculate the air temperature within the section without the higher-power circuit**

**Step 2: calculate the air temperature within the higher-power circuit assuming an air temperature of T° D3**

**Step 3: calculate the air temperature within the section including the higher-power circuit**

Figure B.2 – Temperature-rise verification of a higher-power circuit

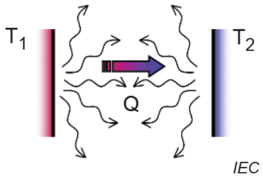
# Annex C
(informative)

# Guidance on the additional temperature-rise effect due to solar radiation

## C.1 General

In case of outdoor installation of the enclosure, and unless installed in the shade or covered e.g. by a canopy or roof, the solar radiation will create an additional increase of temperature in the enclosure. This Annex C proposes an explanation of thermal effects due to solar radiation and their consequences for the calculation of the internal air temperature.

## C.2 Solar radiation phenomena



**Key**

| | |
|---|---|
| T1 | temperature of solid emission (sun) |
| T2 | temperature of solid receptor (enclosure) |
| Q | energy transferred from highest to lowest temperature surfaces |

**Figure C.1 – Solar radiation phenomena**

Radiation is an energy transfer between two entities separated by the atmosphere (see Figure C.1). The materials have the capability of absorbing or emitting photons (quantity of energy). This transfer is almost instantaneous and does not need a material support. On the absorbing side, a part of the radiated energy is usually converted into heat.

When an assembly is installed outdoor the enclosure surface can absorb solar radiation. The type of material of the enclosure surfaces, and more precisely the surface roughness and its colour, can influence the ratio of absorption of the radiated energy and thus the total amount of heat within the enclosure.

The exterior colour and finishing can have a huge impact on the absorption of solar radiation, described by the absorption coefficient. For enclosures in a black or dark colour, the absorption coefficient can be close to 1 and results in the maximum additional temperature-rise, compared to the same enclosure in a white colour, having a coefficient close to 0,1. Table C.1 below specifies different values of absorption coefficient, valid for solar radiation, but not for infrared, relating to the colour.

**Table C.1 – Approximate solar absorption radiation coefficients (according to colour)**

| Colour | Approximate solar absorption radiation coefficients | Additional increase internal air calculation K |
|---|---|---|
| White | 0,14 | 10 |
| Cream | 0,25 | 12 |
| Yellow | 0,3 | 12,9 |
| Light grey, blue, green | 0,5 | 16,5 |
| Medium grey, blue, green | 0,75 | 21 |
| Dark grey, blue, green | 0,95 | 24,4 |
| Black | 0,97 | 25 |

This table is from IEEE STD C37.24-2017.

Adapted and reprinted with permission from IEEE. Copyright IEEE 2017. All rights reserved.

A practical and linear approach can be used to convert and interpolate the influence of the difference between light and dark colours (see Figure C.2).

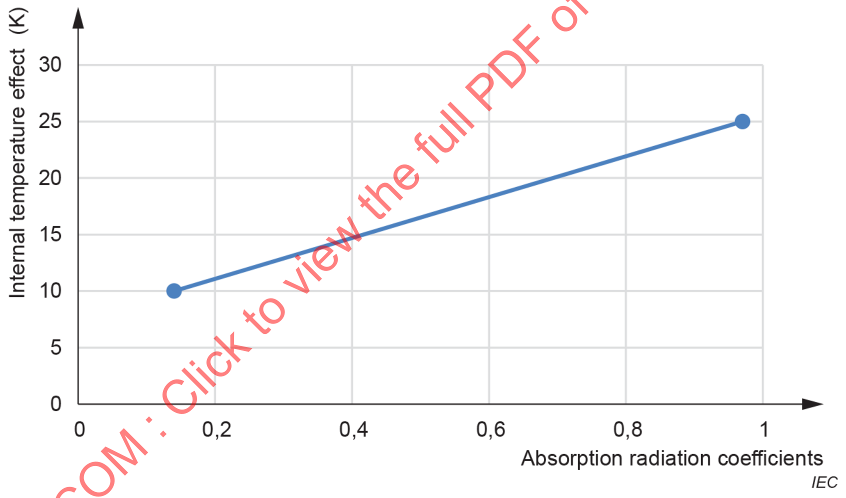


**Figure C.2 – Interpolation curve**

NOTE Manufacturers take into account aging of surfaces due to UV radiation when determining the absorption rate.

## C.3 Solar radiation – consequences for thermal calculation

Due to the energy absorbed by the enclosure, the internal air temperature-rise increases in addition to the temperature-rise caused by internal power losses. Based on a ventilated metal enclosure test comparison and the technical approach documented in IEEE C37.24, an additional increase of 10 K shall be considered if the colour of the enclosure is a light colour or white. In case of grey or dark colours, the increase is higher and can reach 25 K.

To reduce or eliminate the effect of solar radiation on the temperature-rise inside an enclosure, manufacturers usually propose dedicated solutions and particular design by adding a special roof or a canopy. A canopy or roof should be sufficiently large to prevent direct sunlight shining on the assembly from mid-morning to mid- afternoon.

NOTE 1 Recommendations and explanations are mainly based on IEEE C37.24.

NOTE 2 For special installation conditions, e.g. for an indoor assembly installed at places exposed to skylight or to sources of heat radiation, a special agreement between user and manufacturer is defined. This can be taken into account e.g. by a special derating factor, derived from on-site test measurements.

## C.4 Solar radiation of enclosures with air ventilation openings

The effect of solar radiation on the temperature-rise within an enclosure with air ventilation openings can be lower than within an enclosure without openings. If the increases on internal air temperature as defined in Table C.1 are not applied to an enclosure with air ventilation openings, it is the responsibility of the manufacturer of the assembly to provide relevant data.

# Annex D
(informative)

# Guidance on the effect of different enclosure materials, construction and finishes

## D.1 General

The influence of the wall materials and thicknesses used for enclosures can have some effect on the internal steady state temperatures. For example, the thermal radiation effect is influenced by the type of coating whereas the thickness and material of the wall influence the thermal conduction and also the convection effect on the external surfaces.

## D.2 Validity criteria

The generalised approach used in this method of calculation is applicable to enclosures made of metal (steel, aluminium, stainless steel) coated (both sides, inside and outside), insulating material like thermoplastic or thermoset or similar. Some explanations are given based on test results to ensure the validity of this assumption (see Clause D.3).

For bare steel, aluminium, or stainless steel enclosures (i.e. without a coating), due to the reduction of radiated thermal exchange, the calculation method of this document cannot be used. See Clause D.3 for an indication of the impact of using bare metal.

NOTE All types of paint as liquid, varnish, epoxy, and any colour can be considered as a coated surface. An anodised treatment of aluminium enclosures is also considered as a coated surface.

On special enclosures, like fire-resistant enclosures, the walls can include air gaps between the inner and outer surface (double wall enclosure) or a thermal insulating material. In that case, this document's method is not applicable without additional verification by test. The additional verification can be a comparison to provide a derating factor or an impact of the effective cooling surface of this special enclosure type.

## D.3 Material of enclosure

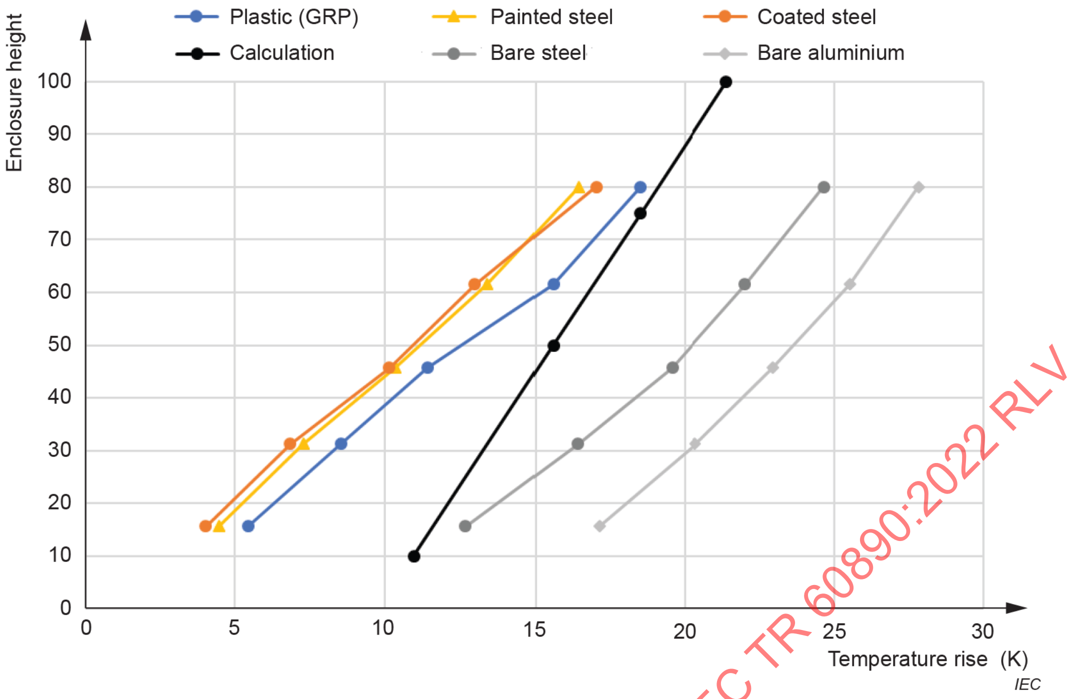
A thermoset enclosure, made of glass-fiber reinforced polyester, is compared with plastic coated and painted steel (RAL 7032, same colour as the thermoset enclosure).

All these tests have been conducted with heating resistors inside, supplying 90 W of simulated power losses almost evenly distributed within the enclosure, to maintain a temperature-rise of approximately 20 K on top ($\Delta t_{1,0}$) of the enclosure. To eliminate natural ventilation effects, the enclosures have been selected or modified to fulfill IP6X.

Coated or painted metal enclosures show a similar thermal behavior to the plastic enclosure, slightly better though, by just of 2 K to 3 K, which is not deemed significant, since the measured values are less than the calculated values. The results obtain using bare enclosures are significantly different and it explains the scope of this document considering enclosures made of metal (steel, aluminum, stainless steel) coated (both sides, inside and outside), insulating materials like thermoplastic or thermoset or similar. The results are shown in Figure D.1.

## D.4 Results

Results are stated in Figure D.1 below.



NOTE Curves in different colours are referring to different enclosure materials.

Figure D.1 – Results of comparison tests

# Annex E
(informative)

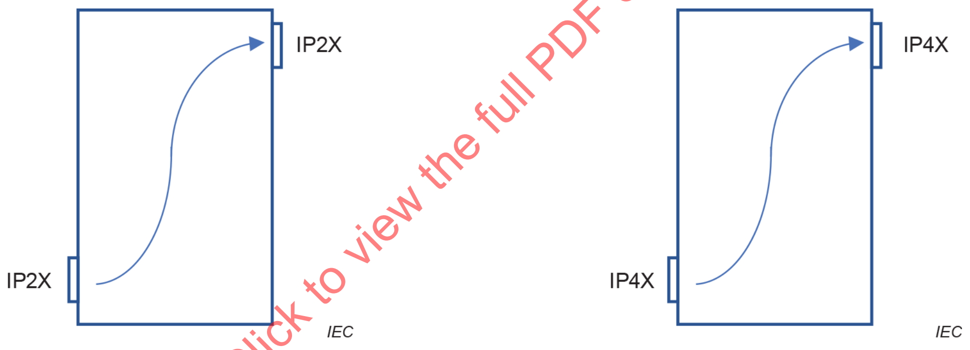
## Guidance on the effects of different natural ventilation arrangements

For natural convection to be effective in an enclosure the cross-section of the open area of the air outlets shall be at least 10 % bigger than the associated air inlets. This relationship is deemed necessary to permit a chimney effect to establish.

If this relationship is not fulfilled, e.g. when the inlet and the outlet openings have the same cross-section, the effect of the natural ventilation can be taken into account using a reference value in the calculation but not using the real inlet openings cross-section but a reference value equal to 90 % of the outlet openings.

NOTE In practice, the rule of 10 % bigger outlet openings can be obtained by design with a different number of inlets and outlets which can also be obtained with a different number of pitch holes.

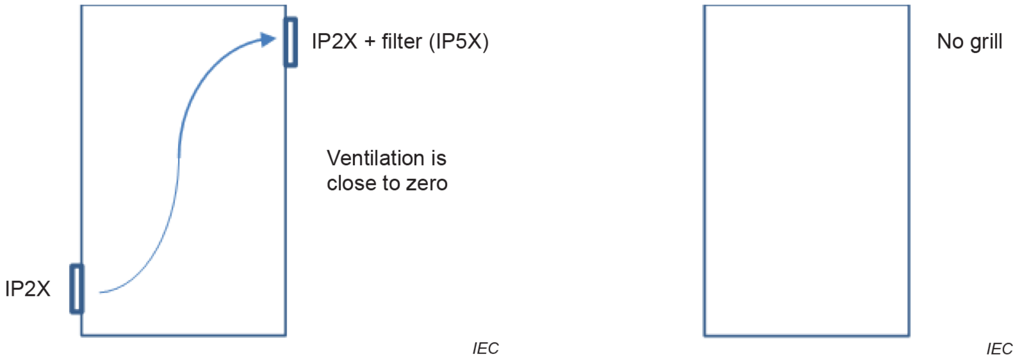
Furthermore, the design of ventilation openings can have an influence on the efficiency of this solution. The size of the holes within the grills has an influence on the air speed. This calculation method given in this document considers an average thermal behaviour and if the effective open area is the same between IP2X (see Figure E.1 a)) and IP4X (see Figure E.1 b)) the results can be considered as equal.



**a) IP2X** **b) IP4X**

Figure E.1 – Examples of crossing diagonal installation

Where additional filters are added to inlets and outlets (e.g. IP5X or higher IP ratings) the natural ventilation air speed is greatly reduced and, in some instances can be close to zero. (see Figure E.2 a)). Therefore, the calculation shall be performed assuming there are no ventilation openings (see Figure E.2 b)).



**a) IP20 + filter** **b) Thermally-equivalent**

Figure E.2 – Effect of additional filters

# Annex F
(informative)

# Guidance on forced ventilation management

## F.1 General

This type of thermal management generates a higher performance of air exchange compared to natural convection. Use of forced ventilation requires maintenance to ensure consistent performance during the whole life of the assembly. Details of the necessary maintenance shall be included in the documentation provided by the manufacturer of the assembly.

## F.2 Forced ventilation installation system

The most common method of thermal management is using a fan. It is essential to take care how to select the correct fan. In most catalogues of thermal management system manufacturers or technical guides, fans are usually described by two different properties. The first-one is its performance in case of free air flow, and the second-one is given in case of working against a load, for example, a grille or an additional filter. This second value, which is the lower one, shall be used to select the correct fan.

Due consideration should be given to the fan supply characteristics, given for example that for different voltages and frequencies i.e. 50 Hz or 60 Hz the air flow rate of the same fan can vary.

A number of systems already exist, and some of them propose an additional monitoring system to prevent any risk of overheating due to the possible failure of the forced ventilation, e.g. because of a lack of maintenance of the filter.

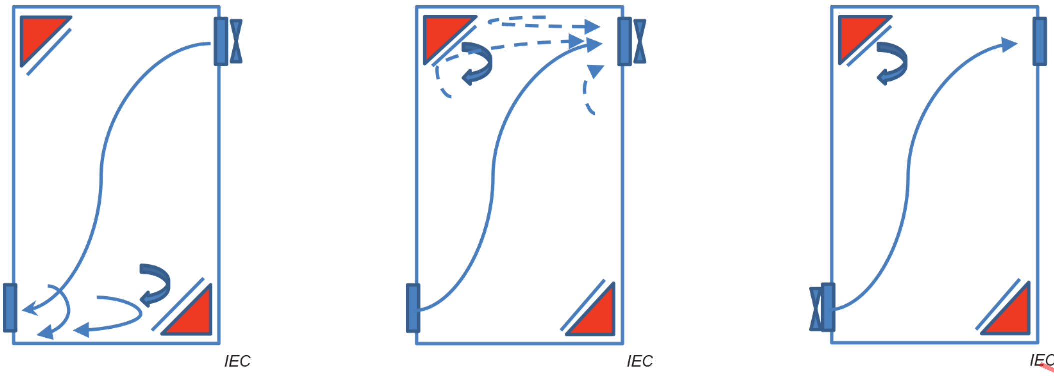
This document does not provide specific rules for incorporating forced ventilation into an assembly. Annex K provides some general guidance on determining the minimum airflow but as an alternative, the manufacturer of the assembly can use guidance from the cooling equipment manufacturer.

## F.3 Installation considerations

Designers of assemblies using forced ventilation shall recognise there can be 'grey areas' within the assembly where the airflow is adversely affected by the forced cooling. The installation of temperature-critical devices within these spaces shall be avoided (see Figure F.1 a)).

The place of installation and the direction of the air flow, e.g. pushing air into or sucking air out of the enclosure, can lead to different results. In case of installing the fan at the top of the enclosure, to blow air out (see Figure F.1 b)), because the enclosures are usually not completely air-tight gaps or some small holes can modify the air-forced circulation. This effect can reduce the cooling in some areas of the enclosure (see Figure F.1 b)).

Another known consequence is that some polluted (unfiltered) air is drawn into the enclosure through these gaps. Based on those facts, the pushed-in air flow design with the fan placed at the bottom of the enclosure is the preferable solution in many cases (See Figure F.1 c)).



a) **Top-fitted fan (1)** b) **Top-fitted fan (2)** c) **Bottom-fitted fan**

**Key**

| | |
|---|---|
| Red-filled zone | “grey” area |
| Solid arrow | air circulation |
| Dashed arrow | gaps, holes additional air entrance |
| Broad arrow | air re-circulation |

**Figure F.1 – Examples of forced ventilation arrangements**

# Annex G
(informative)

# Power loss values calculation

## G.1 General

The reliability of the thermal calculation is directly influenced by the accuracy of the power loss values used. It is important to take into account the most onerous configuration in operation mode including the power losses of the switching and isolating devices, electronic devices, cables, busbar(s), auxiliary power supply, etc.

## G.2 Power losses of low-voltage switchgear and controlgear

In general, the device manufacturer is able to provide power loss values for their devices under specific conditions. Care should be taken to ensure the power loss values given apply to the arrangement being considered, for example power losses can be specified per pole when a three-pole device is being used. In addition, as the power losses are often current dependent, they shall be adjusted to determine the power losses under the normal operating conditions for the assembly. If this is not done, the total losses determined for the assembly can be higher than in practice and lead to oversizing the enclosure.

Examples of low-voltage switchgear and controlgear include switches, circuit-breakers, fuses, contactors, thermal relays and disconnectors. Some product standards for devices indicate how to determine the power losses giving a test method (see for example Annex G of IEC 60947-2:2016). In that case, power losses are usually given in the datasheet or catalogue. If the assembly incorporates devices where the power losses are not given, it is strongly recommended to ask the device manufacturer which value to use and if the losses are proportional to $I^2$ or otherwise depending on the actual load.

Power losses that are representative for the actual conditions in operation shall be taken into account. The following conditions shall be considered. Unless otherwise stated or agreed between the manufacturer of the assembly and device manufacturer, power losses are considered to be measured:

- under full load conditions (e.g. at its rated current, $I_n$ or $I_e$);
- with the device at steady-state temperature;
- with single or three phase supply used based on type of device;
- with the frequency representative of the end use condition.

## G.3 Power losses of conductors connecting low-voltage switchgear and controlgear

The power losses of conductors (wires, cables, bars and similar) connecting switching devices inside the enclosure is a non-negligible part of the total power loss. Power loss calculation method for cables and wires is stated in Annex I and guidance to minimize additional power-loss is stated in Annex J. The power losses are proportional to the length of the cable/wire and the square of the actual current flowing through it.

In case of software usage, a detailed calculation can be easier and should use the lengths of the real configuration. All cables and wires shall be adjusted to the assigned current (rated current of the circuit) in any case.

## G.4 Power losses of busbars

The power loss of connecting conductors of switching devices and the power loss of busbars (distribution and main busbar), if any, are part of the total power losses within an enclosure. Power losses are proportional to the length and the square of the actual current flowing through the busbar. The length of a multiphase busbar system can be considered for each configuration by taking into account the average length of the phases. The power losses shall be adjusted to the assigned current (rated current of the circuit).

Technical data to calculate the power losses of a busbar system can be found in DIN 43670 for aluminium busbar and DIN 43670-2 for hybrid busbar according to the same arrangement and current rating of Table I.3.

NOTE Manufacturers can provide specific values of power losses for their product range of busbars, taking into account the architecture, the material, and dynamic effects of the magnetic field in detail (e.g. by measurement).

## G.5 Power losses of electronic devices

Some devices have independent power loss (i.e. which are not proportional to the square of the current), e.g. the coil of a contactor, or electronic devices as PLC modems, power supplies to electronic components. For all those components, the power losses shall be identified and added to the total losses for thermal calculation.

In relationship with the power losses, two types of electronic functions can be considered:

- non current-dependent, e.g. modems, communications devices, control units. In that case, only the power loss of the device shall be taken into account in the calculation. The power loss of cable and wire connections can be ignored;
- current-dependent, e.g. variable speed drives, motor-starters, dimmers according to the device manufacturer informations. For variable speed drives, see also power loss calculation in IEC 61800-9-2. In the case of current dependant devices, cables and wires connections shall be taken into account in the total power losses associated with these devices.

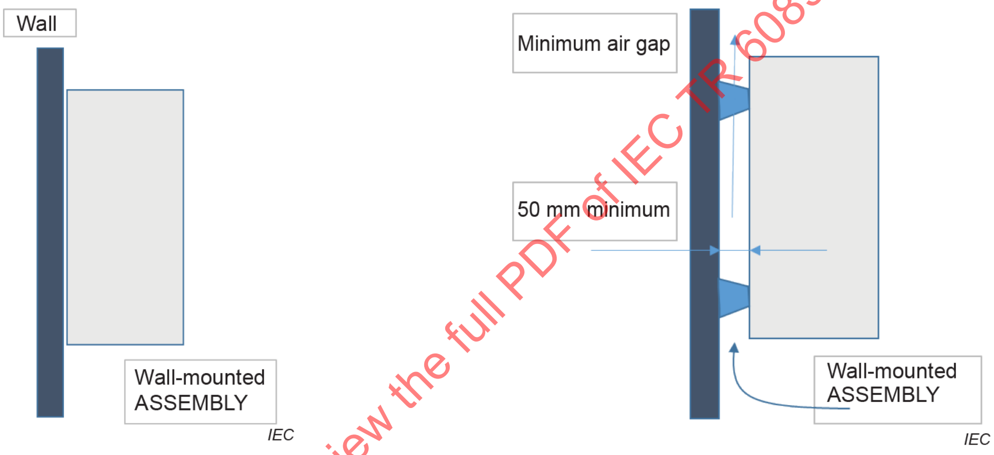
# Annex H
(informative)

## Guidance on the impact of an adjacent wall on the assembly cooling surfaces

Wall-mounted and floor-standing installation of an enclosure on or near a wall reduces the active surface area of heat exchange between the enclosure and the ambient air. In case of wall-installation, an air gap of at least 50 mm between the wall and the enclosure is considered to allow a sufficient air convection (see Figure H.1). In this case, the thermal behaviour can be considered as in free air. See 5.3.2 for the effects of this installation factor.

NOTE 1 Assembly or enclosure manufacturers can provide different values of a minimum gap size in respect of tests, carried out to verify the effects.

NOTE 2 Manufacturer in its documentation define any limitations in respect of clearance between the top of the assembly and the room ceiling and/or air clearances at the sides of the assembly.



a) **Case 1: no air gap**

b) **Case 2: minimum air gap for free air convection**

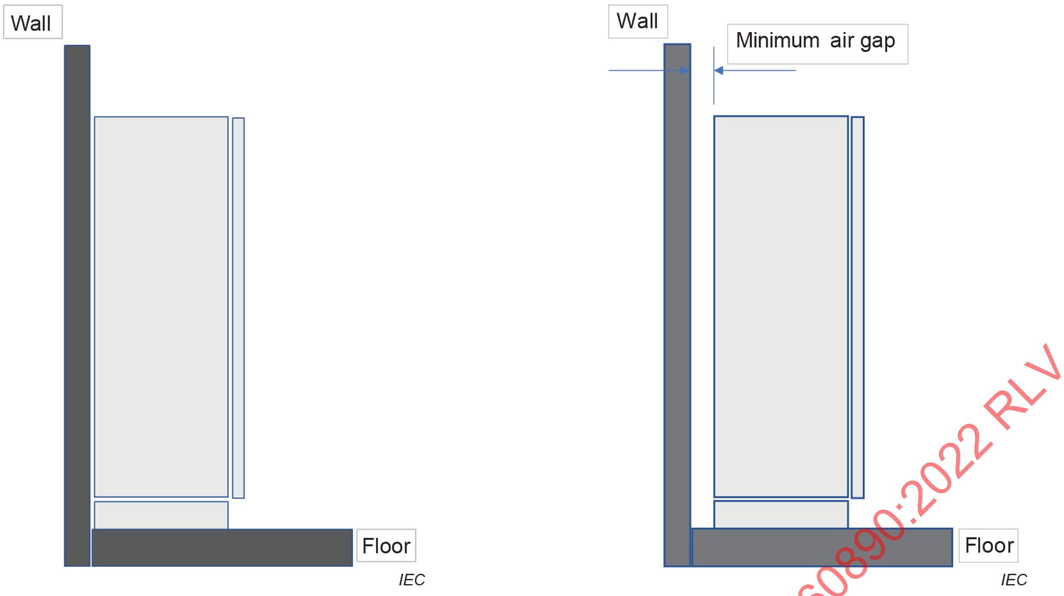
**Figure H.1 – Wall-mounted assembly**

In case of floor-standing assemblies of a width of up to 2 m, an air gap of > 50 mm between wall and enclosure shall be observed (see Figure H.2). In this case, the thermal behaviour can be considered as in free air. See 5.3.2 for the effects of this installation factor.

For assemblies of a width greater than 2 m, the assembly shall be considered as having:

- its back against the wall; or,
- a distance that is sufficient for the assembly to be considered as being in free air e.g. minimum 200 mm; or,
- a distance between the assembly and the wall, sufficient for the assembly to be considered as being in free air, based on tests.

This information shall be provided in the assembly manufacturer’s documentation.



a) **Case 1: no air gap**

b) **Case 2: minimum air gap for free air convection**

**Figure H.2 – Floor-standing assembly**

# Annex I
(informative)

## Operating current and power loss~~es~~ of copper conductors

The maximum permissible operating current of a conductor is influenced by many factors:

- material, type of insulation and arrangement of the conductors belonging to the same circuit;
- mutual influence of components connected to the conductor;
- mutual influence of neighbouring components and conductors belonging to other circuits;
- air temperature inside the enclosure around the conductor;
- temperature and thermal conductivity of constructional parts touching or in close vicinity of the conductor.

The power loss of conductors depends on:

- the operating current and its frequency;
- the material and the temperature of the conductor;
- the shape of the conductor (skin effect);
- the magnetic influence of neighbouring conductors and magnetic constructional parts (proximity effect).

The following Table I.1 and Table I.3 provide guidance values for operating currents and power losses of single-core copper cables and bare copper bars under idealized conditions within an enclosure. The calculation methods used to establish these values are given to enable values to be calculated for other conditions.

The maximum operating currents given in the following tables do not apply to conductors used for assemblies verified by test according to IEC 61439-1.

The power losses are valid for the corresponding operational current given in the following tables. For a different loading the power losses can be calculated using the following formula:

$$P = P_\mathrm{v}\left(\frac{I}{I_\mathrm{max}}\right)^2$$

where

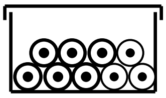
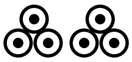
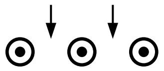
$P$ is the power loss in watts per metre (W/m);

$I$ is the conductor current (loading);

$I_\mathrm{max}$ is the maximum operating current;

$P_\mathrm{v}$ is the power loss at $I_\mathrm{max}$.

### Table I.1 – Operating current and power loss of single-core copper cables with a permissible conductor temperature of 70 °C (ambient temperature inside the enclosure: 55 °C)

| Conductor arrangement | |  | |  | | Spacing at least one cable diameter<br> | |
|---|---|---|---|---|---|---|---|
| | | Single-core cables in a cable trunking on a wall, run horizontally ~~or~~ and vertically.<br>6 of the cables<br>(2 three-phase circuits) continuously loaded | | Single-core cables, touching free in air or on a perforated tray.<br>6 cables[e]<br>(2 three-phase circuits) continuously loaded | | Single-core cables, spaced horizontally in free air | |
| Cross-sectional area of conductor<br>mm$^2$ | Resistance of conductor at 20 °C, $R_{20}$[a]<br>mΩ/m | Max. operating current $I_{\text{max}}$[b]<br>A | Power losses per conductor $P_{\text{v}}$<br>W/m | Max. operating current $I_{\text{max}}$[c]<br>A | Power losses per conductor $P_{\text{v}}$<br>W/m | Max. operating current $I_{\text{max}}$[d]<br>A | Power losses per conductor $P_{\text{v}}$<br>W/m |
| 0,50 | 36,0 | ~~3,7~~ 3,5 | 0,6 | - | - | - | - |
| 0,75 | 24,5 | ~~4,8~~ 5,0 | 0,7 | - | - | - | - |
| 1,0 | 18,1 | ~~5,8~~ 6,0 | 0,7 | - | - | - | - |
| 1,5 | 12,1 | ~~7,6~~ 7,5 | 0,8 | ~~9,6~~ 9 | 1,3 | 15 | 3,2 |
| 2,5 | 7,41 | 10 | 0,9 | 13 | ~~1,6~~ 1,5 | 21 | 3,7 |
| 4 | 4,61 | 14 | 1,0 | 18 | ~~1,9~~ 1,7 | 28 | 4,2 |
| 6 | 3,08 | 18 | 1,1 | ~~24~~ 23 | ~~2,1~~ 2,0 | 36 | 4,7 |
| 10 | 1,83 | 24 | 1,3 | ~~33~~ 32 | ~~2,5~~ 2,3 | 50 | 5,4 |
| 16 | 1,15 | 33 | 1,5 | ~~45~~ 44 | ~~2,9~~ 2,7 | 67 | 6,2 |
| 25 | 0,727 | 43 | 1,6 | ~~61~~ 59 | ~~3,3~~ 3,0 | 89 | 6,9 |
| 35 | 0,524 | 54 | 1,8 | ~~76~~ 74 | ~~3,6~~ 3,4 | 110 | 7,7 |
| 50 | 0,387 | 65 | 2,0 | ~~93~~ 90 | ~~4,0~~ 3,7 | 134 | 8,3 |
| 70 | 0,268 | 83 | 2,2 | ~~120~~ 116 | ~~4,6~~ 4,3 | 171 | 9,4 |
| 95 | 0,193 | 101 | 2,4 | ~~147~~ 142 | ~~5,0~~ 4,7 | 208 | 10,0 |
| 120 | 0,153 | 117 | 2,5 | ~~171~~ 165 | ~~5,4~~ 5,0 | 242 | 10,7 |
| 150 | 0,124 | - | - | ~~198~~ 191 | ~~5,8~~ 5,4 | 278 | 11,5 |
| 185 | 0,099 1 | - | - | ~~227~~ 220 | ~~6,1~~ 5,7 | 318 | 12,0 |
| 240 | 0,075 4 | - | - | ~~269~~ 260 | ~~6,6~~ 6,1 | 375 | 12,7 |
| 300 | 0,060 1 | - | - | ~~311~~ 301 | ~~7,0~~ 6,6 | 432 | 13,5 |

[a] Values from IEC 60228:2004, Table 2 (stranded, plain copper conductors).

[b] Current carrying capacity $I_{30}$ for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.4, col. 4 (Reference method of installation: item B1 in Table B.52.1). ~~Values for cross-sections less than 1,5 mm$^2$ calculated following Annex D of IEC 60364-5-52:2009.~~

$k_2$ = 0,8 (item 1 in Table B.52.17 of IEC 60364-5-52:2009, two circuits).

[c] Current carrying capacity $I_{30}$ for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.10, col. 5 (~~Reference~~ Method of installation: Item F in Table B.52.1). Values for cross-sections less than 25 mm$^2$ calculated following Annex D of IEC 60364-5-52:2009. ~~$k_2$ = 0,91 (Table B.52.21 of IEC 60364-5-52:2009, vertical perforated cable tray systems; Method of installation: 31; number of trays or ladders: 1; number of three-phase circuits per tray or ladder: two circuits).~~

$k_2$ = 0,88 (based on experience item 4 in Table B.52.21, two circuits, is used in preference to Table B.52.21).

[d] Current carrying capacity $I_{30}$ for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.10, col. 7 (~~Reference~~ Method of installation: item G in column 1 of Table B.52.1 ~~of IEC 60364-5-52:2009~~). Values for cross-sections less than 25 mm$^2$ calculated following Annex D of IEC 60364-5-52:2009. ($k_2$ = 1).

[e] The coefficients are based on horizontally run cables as it has negligible impact on vertically run cables within an assembly.

$$I_{\max} = I_{30} \times k_1 \times k_2 \qquad P_v = I_{\max}^2 \times R_{20} \times [1 + \alpha \times (T_c - 20\,°\mathrm{C})]$$

where

$I_{30}$ is the maximum operating current of a single conductor for air temperature around the conductor of 30 °C;

$k_1$ is the reduction factor for air temperature inside the enclosure around the conductors (IEC 60364-5-52:2009, Table B.52.14); $k_1$ = 0,61 for conductor temperature 70 °C, ambient temperature 55 °C; $k_1$ for other air temperatures: See Table I.2;

$k_2$ is the reduction factor for groups of more than one circuit (~~IEC 60364-5-52:2009, Table B.52.17~~ see further explanation in footnotes b, c, and d of Table I.1);

$\alpha$ is the temperature coefficient of resistance of copper, $\alpha$ = 0,004 K$^{-1}$;

$T_c$ is the conductor temperature.

**Table I.2 – Reduction factor $k_1$ for cables with a permissible conductor temperature of 70 °C (extract from IEC 60364-5-52:2009, Table B.52.14)**

| Air temperature inside the enclosure around the conductors<br>°C | Reduction factor<br>$k_1$ |
|---|---|
| 20 | 1,12 |
| 25 | 1,06 |
| 30 | 1,00 |
| 35 | 0,94 |
| 40 | 0,87 |
| 45 | 0,79 |
| 50 | 0,71 |
| 55 | 0,61 |
| 60 | 0,50 |

If the operating current in Table I.1 is converted for other air temperatures using the reduction factor $k_1$, then the corresponding power losses shall be calculated also using the formula given above.

### Table I.3 – Operating current and power loss of bare copper bars with rectangular cross-section, run horizontally and arranged with their largest face vertical, for DC and AC frequencies 16 2/3 Hz, 50 Hz to 60 Hz (ambient temperature inside the enclosure: 55 °C, temperature of the conductor 70 °C)

| Height x thickness of bars | Cross-sectional area of bar | One bar per ~~phase~~ line<br>▌ | | | | | Two bars per ~~phase~~ line (spacing = thickness of bars)<br>▌▌ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50 Hz to 60 Hz AC | | | DC and AC up to 16 2/3 Hz | | 50 Hz to 60 Hz AC | | | DC and AC up to 16 2/3 Hz | |
| | | $k_3$ | Operating current | Power losses per ~~phase~~ line conductor $P_v$ | Operating current | Power losses per ~~phase~~ line conductor $P_v$ | $k_3$ | Operating current | Power losses per ~~phase~~ line conductor $P_v$ | Operating current | Power losses per ~~phase~~ line conductor $P_v$ |
| mm × mm | mm² | | A | W/m | A | W/m | | A | W/m | A | W/m |
| 12 × 2 | 23,5 | 1,00 | 70 | 4,5 | 70 | 4,5 | 1,01 | 118 | 6,4 | 118 | 6,4 |
| 15 × 2 | 29,5 | 1,00 | 83 | 5,0 | 83 | 5,0 | 1,01 | 138 | 7,0 | 138 | 6,9 |
| 15 × 3 | 44,5 | 1,01 | 105 | 5,4 | 105 | 5,3 | 1,02 | 183 | 8,3 | 183 | 8,1 |
| 20 × 2 | 39,5 | 1,01 | 105 | 6,1 | 105 | 6,0 | 1,01 | 172 | 8,1 | 173 | 8,1 |
| 20 × 3 | 59,5 | 1,01 | 133 | 6,4 | 133 | 6,3 | 1,02 | 226 | 9,4 | 226 | 9,2 |
| 20 × 5 | 99,1 | 1,02 | 178 | 7,0 | 178 | 6,9 | 1,04 | 325 | 11,9 | 326 | 11,5 |
| 20 × 10 | 199 | 1,03 | 278 | 8,5 | 278 | 8,3 | 1,07 | 536 | 16,6 | 541 | 15,7 |
| 25 × 5 | 124 | 1,02 | 213 | 8,0 | 213 | 7,8 | 1,05 | 381 | 13,2 | 384 | 12,7 |
| 30 × 5 | 149 | 1,03 | 246 | 9,0 | 247 | 8,8 | 1,06 | 437 | 14,5 | 439 | 13,9 |
| 30 × 10 | 299 | 1,05 | 372 | 10,4 | 376 | 10,2 | 1,11 | 689 | 18,9 | 702 | 17,7 |
| 40 × 5 | 199 | 1,03 | 313 | 10,9 | 315 | 10,7 | 1,07 | 543 | 17,0 | 551 | 16,4 |
| 40 × 10 | 399 | 1,07 | 465 | 12,4 | 473 | 12,0 | 1,15 | 839 | 21,7 | 878 | 20,7 |
| 50 × 5 | 249 | 1,04 | 379 | 12,9 | 382 | 12,6 | 1,09 | 646 | 19,6 | 663 | 18,9 |
| 50 × 10 | 499 | 1,08 | 554 | 14,2 | 569 | 13,9 | 1,18 | 982 | 24,4 | 1 047 | 23,5 |
| 60 × 5 | 299 | 1,05 | 447 | 15,0 | 452 | 14,7 | 1,10 | 748 | 22,0 | 774 | 21,4 |
| 60 × 10 | 599 | 1,10 | 640 | 16,1 | 663 | 15,7 | 1,21 | 1 118 | 27,1 | 1 216 | 26,4 |
| 80 × 5 | 399 | 1,07 | 575 | 19,0 | 586 | 18,5 | 1,13 | 943 | 27,0 | 995 | 26,6 |
| 80 × 10 | 799 | 1,13 | 806 | 19,7 | 852 | 19,4 | 1,27 | 1 372 | 32,0 | 1 547 | 32,1 |
| 100 × 5 | 499 | 1,10 | 702 | 23,3 | 722 | 22,4 | 1,17 | 1 125 | 31,8 | 1 177 | 29,7 |
| 100 × 10 | 999 | 1,17 | 969 | 23,5 | 1 040 | 23,2 | 1,33 | 1 612 | 37,1 | 1 879 | 37,8 |
| 120 × 10 | 1 200 | 1,21 | 1 131 | 27,6 | 1 229 | 27,0 | 1,41 | 1 859 | 43,5 | 2 204 | 43,4 |

$$P_v = \frac{I^2 \times k_3}{\kappa \times A} \times [1 + \alpha \times (T_c - 20\ °C)]$$

where

$P_v$ is the power loss per metre in W;

$I$ is the operating current in A;

$k_3$ is the current displacement factor for 50 Hz/60 Hz ($k_3$ = 1 for direct current and AC 16 2/3 Hz);

$\kappa$ is the conductivity of copper, $\kappa = 56\ \frac{m}{\Omega \times mm^2}$;

$A$ is the cross-sectional area of bar in mm$^2$;

α is the temperature coefficient of resistance of copper, α = 0,004 K$^{-1}$;

$T_c$ is the conductor temperature in °C.

The operating currents ~~may~~ can be converted for other ambient air temperatures inside the enclosure and/or for a conductor temperature of 90 °C by multiplying the values of Table I.3 by the corresponding factor $k_4$ from Table I.4 below. Then the power losses shall be calculated using the formula given above accordingly.

**Table I.4 – Factor $k_4$ for different temperatures of the air inside the enclosure and/or for the conductors**

| Air temperature inside the enclosure around the conductors °C | Factor $k_4$ | |
|---|---|---|
| | Conductor temperature of 70 °C | Conductor temperature of 90 °C |
| 30 | 1,82 | 2,26 |
| 35 | 1,69 | 2,14 |
| 40 | 1,54 | 2,03 |
| 45 | 1,35 | 1,91 |
| 50 | 1,18 | 1,77 |
| 55 | 1,00 | 1,62 |
| 60 | 0,77 | 1,48 |

It shall be considered that, dependent upon the design of the enclosure, quite different ambient and conductor temperatures can occur, especially with higher operating currents.

Verification of the actual temperature-rise under these conditions shall be determined by test according to IEC 61439-1. The power losses ~~may~~ can then be calculated by the same method as used for Table I.3.

NOTE 1 At higher currents additional eddy current losses can be significant which are not included in the values of Table I.3.

NOTE 2 For other busbars with different cross-section, configurations and environment parameters, technical datas are available in DIN (DIN 43670 for aluminum, DIN 43671 for copper and DIN 43670-2 for copper coated aluminum).

# Annex J
(informative)

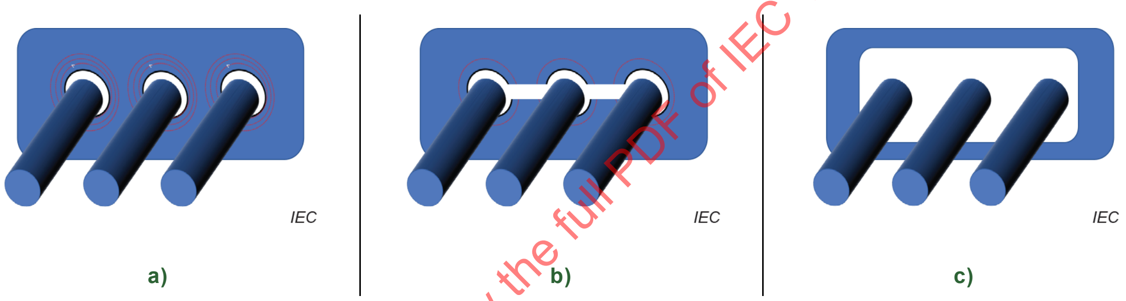
## Guidance to magnetic and eddy-current power losses

Magnetic eddy currents and hysteresis losses can be significant where the use of conductors in AC circuits with a current rating exceeding 200 A pass through ferromagnetic enclosures, sections or plates, to minimize their effects they shall:

- be arranged such that the conductors are only collectively surrounded by ferromagnetic material, e.g. pass through the same hole; or
- arrangements where conductors pass through separate holes shall have been verified by temperature-rise test(s).

It is permitted for an additional protective conductor to enter the ferrous enclosure individually. Conductors carrying currents in excess of 200 A and the adjacent structural parts are so arranged that eddy-current and hysteresis losses are minimized.

To increase the rating of the conductor, for example, the design of the cable entry plates can be optimized (see Figure J.1). Alternatively, a non-magnetic material can be used.



a) b) c)

**Figure J.1 – Power losses distribution for different gland plates with the same rating**

Figure J.1a) shows the arrangement suitable for currents up to 200 A. For currents of the order of 600 A, the arrangement shown in Figure J.1b) is generally acceptable. At higher currents where the magnetic effects are more significant the arrangement shown in Figure J.1c) is more appropriate. With the higher currents sufficient distances between conductors and the magnetic parts of the assembly, such as the steel frame, shall be provided to avoid excessive heating of the magnetic parts.

# Annex K
(informative)

# Forced ventilation airflow calculation

## K.1 General

A simplified method of verification for forced ventilation is given in IEC 61439-2:2020. The method below takes a more fundamental approach.

This informative annex provides more details for calculation methods to determine the minimum airflow needed for forced ventilation of an enclosure, considering its natural power dissipation, and by utilising the calculation method of this document (without natural ventilation). Also see Annex F for additional guidance.

The dissipated power of an enclosure can be approximated as

$$P_\text{w} = \underbrace{\rho \times \dot{V} \times c_\text{p} \times \left(T_\text{int} - T_\text{a}\right)}_{\text{A}} + \underbrace{\alpha \times A_\text{S} \times \left(T_\text{int} - T_\text{a}\right)}_{\text{B}}$$

where (to add these symbols to Table 2):

$P_\text{w}$ total dissipated power in W;

$\rho$ mass density (of air) at $T_\text{a}$ in kg/m$^3$;

$\dot{V}$ volume flow rate of the air flow through the enclosure in m$^3$/s;

$c_\text{p}$ heat capacity (of air) in J/kg*K;

$T_\text{int}$ temperature inside the enclosure in °C;

$T_\text{a}$ ambient temperature in °C;

$\alpha$ heat transfer coefficient (includes conduction and radiation of heat) in W/m$^2$K;

$A_\text{s}$ surface area, which can transport heat (usually excluding the bottom area) in m$^2$.

**The first part (A)** of the formula describes the amount of heat that is transported out of the enclosure by air mass. The source of the air flow can be natural, i.e. by the pressure drop that is created solely by the temperature-rise, or forced.

For regular enclosures without ventilation openings and with IP degrees higher or equal to IP4X, the volume flow and thus the heat dissipation by this effect can be close to zero. Where there are no construction-based gaps or holes, adding ventilation grills enables a natural air flow that is significant for temperature-rise calculation.

By adding one or more fans and appropriate adjacent ventilation grills compatible to the air flow of the fan(s), the volume flow rate can be increased significantly, enabling manufacturers to design assemblies with significantly higher power losses installed in the same enclosure.

**The second part (B)** of the formula describes the conduction and radiation of heat, which both depends on various parameters (e.g. the geometry of the enclosure, the material, the colour, the surface characteristic i.e. roughness). Thus, it is difficult to specify the heat transfer coefficient α without measurement. This document proposes a calculation method that replaces part (B) of the equation by an algorithm based on empirically determined factors. In addition, an approach to consider natural ventilation is included to represent part (A).

Once the dissipated power of the enclosure is calculated using this document, the amount of air volume flow can be determined using the formula below:

$$P_{\text{fan}} = \rho \times \dot{V} \times c_{\text{p}} \times \left(T_{\text{int,max}} - T_{\text{a}}\right) = P - P_{890}\left(A_{e,}T_{\text{int,max}} - T_{\text{a}}\right)$$

where

$P_{\text{fan}}$ is the power loss dissipated by forced ventilation;

$T_{\text{int,max}}$ is the maximum temperature allowed inside the enclosure (limited e.g. by devices);

$P$ is the total installed power loss inside the enclosure (see Annex G);

$P_{890}$ is the calculated power dissipation of the enclosure according to this document, without considering natural ventilation;

$A_{\text{e}}$ is the effective surface area.

## K.2 Ventilation airflow calculation

Since the volume flow rate of natural ventilation can be neglected compared to forced ventilation, the minimum volume flow rate that shall be generated by the ventilation system can be calculated by transposing the equation above to:

$$\dot{V}_{\text{min}} = \frac{P - P_{890}\left(A_{e,}T_{\text{int,max}} - T_{\text{a}}\right)}{\rho \times c_{\text{p}} \times \left(T_{\text{int,max}} - T_{\text{a}}\right)}$$

Since both mass density and specific heat capacity of air are not constant, it is complicated to get the correct values under the corresponding ambient conditions. Thus, the term $\rho \times c_{\text{p}}$ can be approximated for calculation, taking a derating factor $k$ for the height above sea level into account, to:

$$\rho \times c_{\text{p}} = k \times 1{,}133\,5 \frac{kg}{m^3} \times 1{,}024 \frac{kJ}{kg \times K} \approx k \times 1\,160 \frac{J}{m^3 \times K}$$

NOTE 1 This value is calculated assuming an ambient temperature of 35 °C and a relative humidity of 50 %.

Furthermore, the formula for the minimum flow rate is reduced to:

$$\dot{V}_{\text{min}} = \frac{P - P_{890}}{1\,160 \times k \times \left(T_{\text{int,max}} - T_{\text{a}}\right)}$$

Values for the factor $k$ are given in Table K.1:

**Table K.1 – Factor $k$ for altitudes above sea level**

| **Height** (m) | **0** | **500** | **1 000** | **1 500** | **2 000** | **2 500** | **3 000** |
|---|---|---|---|---|---|---|---|
| $k$ | 1,00 | 0,95 | 0,89 | 0,84 | 0,80 | 0,75 | 0,71 |

For the internal temperature $T_{\text{int,max}}$, the highest temperature allowed in the enclosure, limited by the maximum operation temperature of the incorporated devices shall be considered.

To select a correct fan and filter system, the calculated volume flow rate shall be compared with the correct flow rate given in the data sheets, considering grills or filters (see Annex F). Depending on the equipment inside the enclosure, the air flow can be further inhibited.

Air-flow as calculated above provides effective cooling when the total supply current does not exceed 1 600 A and when the following conditions are fulfilled:

a) there is no horizontal partition in the assembly or a section of an assembly that restricts the air flow. This does not exclude the installation of air deflection plates with the intention to control the cooling air flow;

b) the instructions of the cooling equipment manufacturer with regard to the installation and the use of the cooling device are fulfilled.

NOTE 2 When the above conditions are not fulfilled considerations can be given by comparison to a tested design using an increased air-flow, if appropriate.

# Bibliography

IEC 60204-1, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60228:2004, *Conductors of insulated cables*

IEC 60364-5-52:2009, *Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems*

IEC 60947 (all parts), *Low-voltage switchgear and controlgear*

IEC 60947-2:2019, *Low-voltage switchgear and controlgear – Part 2: Circuit-breakers*

IEC 61439-1:2020, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

IEC 61439-2:2020, *Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies*

IEC 61800-9-2, *Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters*

IEC 62208, *Empty enclosures for low-voltage switchgear and controlgear assemblies – General requirements*

DIN 43670[1], *Aluminium bus bars; design for continuous current*

DIN 43670-2[1], *Aluminium bus bars copper cladding; design for continuous current*

DIN 43671[1], *Copper bus bars; design for continuous current*

---

[1] Only German text is available.

# IEC TR 60890

Edition 3.0 2022-09

# TECHNICAL REPORT

colour
inside

## A method of temperature-rise verification of low-voltage switchgear and controlgear assemblies by calculation

IEC TR 60890:2022-09(en)

## CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

___________

# A METHOD OF TEMPERATURE-RISE VERIFICATION OF LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES BY CALCULATION

## 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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 60890 has been prepared by subcommittee 121B: Low-voltage switchgear and controlgear assemblies, of IEC technical committee 121: Switchgear and controlgear and their assemblies for low-voltage. It is a Technical Report.

This third edition cancels and replaces the second edition published in 2014. This edition constitutes a technical revision.

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

- alignment with IEC 61439-1:2020;
- addition of individual annexes for guidance of technical explanations related to:
  - effect of an uneven power distribution;
  - additional temperature-rise due to solar radiation;
  - effect of different enclosure materials;
  - effect of different natural ventilation management;
  - forced ventilation management;

  - power losses calculation;
  - impact of an adjacent wall can have on the assembly cooling surface(s);
- maximum internal ambient temperature limit into an assembly;
- validity area of the calculation extended from 3 150 A to 3 200 A;
- addition of an algebraic equation to the different curves included in the document.

The text of this Technical Report is based on the following documents:

| Draft | Report on voting |
|---|---|
| 121B/136/DTR | 121B/147/RVDTR |

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

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

**IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.**

# INTRODUCTION

In the series of design verifications of IEC 61439-1 a temperature-rise verification of low-voltage power switchgear and controlgear assemblies is specified. This can be by test, however, alternatives are acceptable under defined circumstances. Selection of the method used for temperature-rise verification is the responsibility of the original manufacturer. Where applicable this document can also be used for temperature-rise verification of similar products in accordance with other standards (e.g. IEC 60204-1). The method of calculation can also be used to determine the thermal power dissipation capability of an enclosure in accordance with IEC 62208 for a given internal air temperature-rise. The factors and coefficients, set out in this document have been derived from measurements on numerous assemblies and the method has been verified by comparison with test results.

# A METHOD OF TEMPERATURE-RISE VERIFICATION OF LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES BY CALCULATION

## 1 Scope

This document specifies a method of air temperature-rise calculation inside enclosures for low-voltage switchgear and controlgear assemblies or similar products in accordance with their respective standard.

The method is primarily applicable to enclosed assemblies or partitioned sections of assemblies without forced ventilation. However, some technical guidance to adapt it for the use of forced ventilation is given in this document. The results obtained by using this method are directly influenced by the accuracy of the evaluation of power losses used as inputs to perform the thermal calculations.

NOTE The air temperature within the enclosure is equal to the ambient air temperature outside the enclosure plus the temperature-rise of the air inside the enclosure caused by the power losses of the installed equipment.

For the method to be applied, the maximum daily average ambient air temperature outside the assembly at the place of installation is specified between 10 °C and 50 °C. The maximum daily temperature does not exceed the maximum daily average temperature by more than 5 K.

Several annexes in this document provide guidance on how temperature-rise within assemblies can be affected by influences which are not considered in the calculation method included in this document, for example, when the assembly is subject to solar radiation. In such cases, different means of verification to that given in this document can be applied to ensure a definitive result and verification of the design.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61439 (all parts), *Low-voltage switchgear and controlgear assemblies*

IEEE C37.24-2017, *IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61439 (all parts) apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

# 4 Verification conditions

When this method of calculation is applied to low-voltage switchgear and controlgear assemblies the following conditions shall be fulfilled:

- the assembly is designed for AC currents and frequencies up to and including 1 600 A, 60 Hz. For higher current ratings or frequencies, the method could be used with additional verifications taking into account the effect of eddy-currents on the temperature distribution inside the assembly as required by the relevant product standards.

  NOTE 1 In IEC 61439-2, additional requirements for currents in excess of 1 600 A are specified to take into account the considerably increased power losses due to magnetic effects (eddy currents, proximity effect, skin effect)
- the assembly is designed for DC currents up to and including 3 200 A. For higher current ratings the method could be used with additional verifications as required by the relevant product standards;
- conductors carrying currents in excess of 200 A AC, and the adjacent structural parts are so arranged that eddy-current and hysteresis losses are negligible;
- there is an approximately even distribution of power losses inside the enclosure;
- the power losses data for all built-in components are available or can be calculated (see Clause 5);
- the installed equipment is so arranged that air circulation is not significantly impeded.

NOTE 2 When this method is used to determine the thermal power dissipation capability of an empty enclosure in accordance with IEC 62208, the above conditions do not apply.

# 5 Calculation method

## 5.1 Assumptions made in this calculation

To use the calculation method of this document, the following assumptions are deemed valid:

- the enclosure is made of metal (steel, aluminium, stainless steel) coated (both sides, inside and outside), insulating material like thermoplastic or thermoset or similar (see Annex D);
- the enclosure is made of a single layer material or multiple layers without air-gap;
- for enclosures with or without natural ventilation, there are no more than five horizontal partitions in the assembly or in a section of it;
- the enclosure is designed without ventilation openings or;
- the enclosure is designed with free air inlet and outlet ventilation openings, without the inclusion of any additional filter (see Annex E);
  - the cross-section of the air outlet openings is at least 10 % bigger than that of the inlet openings to permit the chimney effect;
  - the minimum cross section of air inlet openings is 10 cm$^2$;

  NOTE 1 Figure 3 and the formula given in Table 7 are not usable for lower cross sections. Assemblies with a sum of the air inlet openings less than 10 cm$^2$ are considered as assemblies without an air inlet.

  - if the enclosure has air inlet and outlet openings with filters for an IP5X rating or higher then these openings are not considered for the calculation;
  - for IP ratings lower than IP5X the effective free air cross section of the openings shall be used for calculation (see Annex E);
- where enclosures with natural ventilation openings have compartments, the surface of each horizontal partition shall be provided with free air ventilation openings of at least 50 % of the horizontal cross-section of the partition (see Clause B.1);
- power losses are considered as a sum of the followings:
  - power losses of low-voltage switchgear and controlgear (see Clause G.2);

  - power losses of conductors connecting low-voltage switchgear and controlgear (see Clause G.3);
  - power losses of busbars (see Clause G.4);
  - power losses of electronic devices (see Clause G.5);
- the enclosure is not subject to solar radiation.

## 5.2 Necessary information

The following data shall be used to calculate the temperature-rise of the air inside an enclosure:

- dimensions of the enclosure: height/width/depth;
- type of installation of the enclosure according to Figure 4;
- design of enclosure, i.e. with or without ventilation openings;
- number of internal horizontal partitions;
- effective power loss of equipment installed in the enclosure, see Annex G;
- effective power loss ($P_v$) of conductors according to Annex I.

## 5.3 Calculation procedure

### 5.3.1 General

For the enclosures specified in columns 4 and 5 of Table 1, the calculation of the temperature-rise of the air inside the enclosure is carried out using the formulae laid down in columns 1 to 3 of Table 1.

The pertinent factors and exponents (characteristics) are obtained from columns 6 to 10 of Table 1.

The symbols, units and designations are stated in Table 2.

For enclosures having more than one section with vertical partitions, the temperature-rise of the air inside the enclosure shall be determined separately for each section.

Where enclosures without vertical partitions or individual sections have an effective cooling surface greater than 11,5 m$^2$ or a width greater than about 1,5 m, they should be divided for the calculation into fictitious sections, whose dimensions approximate to the foregoing values.

NOTE The template (see Figure 9) can be used as a calculation aid.

### 5.3.2 Determination of the effective cooling surface $A_e$ of the enclosure

The calculation is carried out according to Formula (1) in column 1 of Table 1.

The effective cooling surface $A_e$ of an enclosure is the sum of the individual surfaces $A_o$ multiplied by the surface factor $b$. This factor takes into account the heat dissipation of the individual surfaces according to the type of installation of the enclosure (see Annex H for additional explanations).

### 5.3.3 Determination of the internal temperature-rise $\Delta t_{0,5}$ of the air at mid-height of the enclosure

The calculation is carried out according to Formula (2) in column 2 of Table 1.

In Formula (2) the enclosure constant $k$ allows for the size of the effective cooling surface for enclosures without ventilation openings and, in addition, for the cross-section of the air inlet openings for enclosures with ventilation openings.

The dependence of the temperature-rise occurring in the enclosure on the effective power loss $P$ is expressed by the exponent $x$.

The factor $d$ allows for the dependence of the temperature-rise on the number of internal horizontal partitions.

### 5.3.4 Determination of the internal temperature-rise $\Delta t_{1,0}$ of air at the top of the enclosure

The calculation is made according to Formula (3) in column 3 of Table 1.

Factor $c$ allows for the temperature distribution inside an enclosure. Its determination varies with the design and installation of the assembly as follows:

a) For enclosures without ventilation openings and with an effective cooling surface:

$$A_e > 1,25 \text{ m}^2$$

The factor $c$ from Figure 4, depends on the type of installation and the height/base factor $f$, where:

$$f = \frac{h^{1,35}}{A_b}$$

b) For enclosures with ventilation openings and with an effective cooling surface:

$$A_e > 1,25 \text{ m}^2$$

The factor $c$ from Figure 6, depends on the cross-section of air inlet openings and the height/base factor $f$, where:

$$f = \frac{h^{1,35}}{A_b}$$

c) For enclosures without ventilation openings and with an effective cooling surface:

$$A_e \leq 1,25 \text{ m}^2$$

The factor $c$ from Figure 8, depends on the height/width factor $g$, where:

$$g = \frac{h}{w}$$

where

$h$ is the enclosure height, in m;

$A_b$ is the surface area of the enclosure base, in m$^2$;

$w$ is the enclosure width, in m.

### 5.3.5 Characteristic curve for temperature-rise of air inside enclosure

#### 5.3.5.1 General

To evaluate the design according to Clause 7, the calculated results of 5.3.3 and 5.3.4 shall be applied with the proper characteristic curve for temperature-rise of air inside the enclosure as a function of the enclosure height. The air temperatures within horizontal levels are practically constant.

#### 5.3.5.2 Temperature-rise characteristic curve for enclosures with an effective cooling surface $A_e$ exceeding 1,25 m$^2$

As a general rule, the characteristic curve of temperature-rise is adequately well defined by a straight line which runs through the points $\Delta t_{1,0}$ and $\Delta t_{0,5}$ (see Figure 1).

The internal air temperature-rise at the bottom of the enclosure is close to zero, i.e. the characteristic curve flattens out towards zero. In practice, the dotted part of the characteristic curve is of secondary importance.

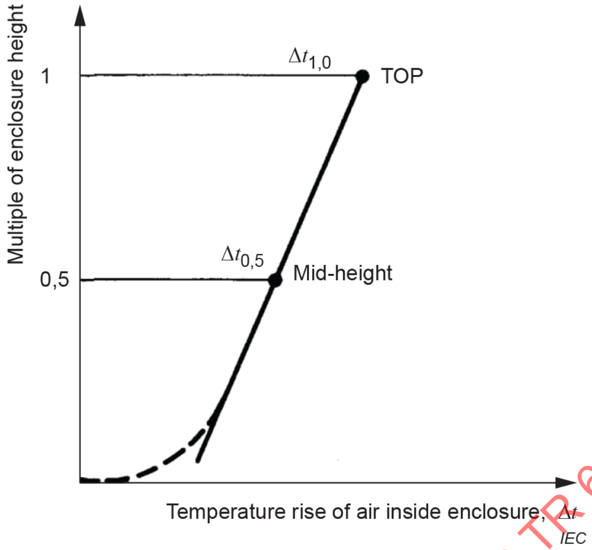


**Figure 1 – Temperature-rise characteristic curve for enclosures with $A_e$ exceeding 1,25 m$^2$**

### 5.3.5.3 Temperature-rise characteristic curve for enclosures with an effective cooling surface $A_e$ not exceeding 1,25 m$^2$

For this type of enclosure, the maximum temperature-rise in the upper quarter is constant and the values for $\Delta t_{1,0}$ and $\Delta t_{0,75}$ are identical (see Figure 2).

The characteristic curve is obtained by connecting the temperature-rise values at an enclosure level of 0,75 and 0,5 (see Figure 2).

The internal air temperature-rise at the bottom of the enclosure is close to zero, i.e. the characteristic curve flattens out towards zero. In practice, the dotted part of the characteristic curve is of secondary importance.

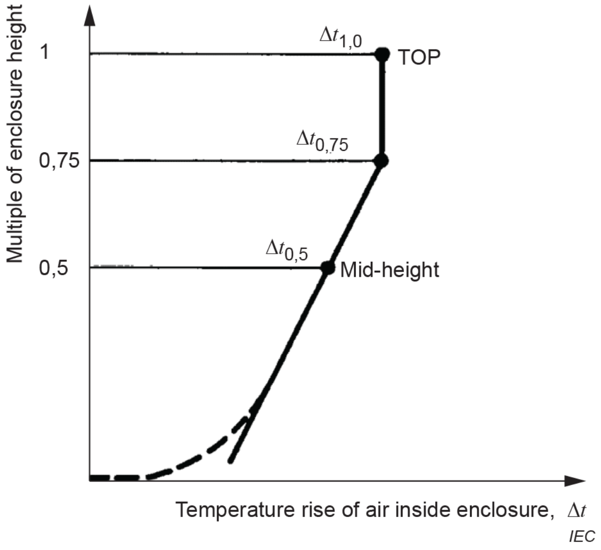


**Figure 2 – Temperature-rise characteristic curve for enclosures with $A_e$ not exceeding 1,25 m$^2$**

### 5.4 Maximum internal air temperature limits

This document contains a method to calculate the internal air temperature within an enclosure. The resulting temperature shall not exceed the maximum absolute temperature allowed by different types of devices and products installed inside.

The user of this document should refer to the manufacturer’s instructions regarding the maximum operational temperature allowed for the devices used inside the assembly.

NOTE The value of internal air temperature has a direct influence on the ageing and operation of built-in components.

## 6 Further considerations

### 6.1 General

The means of temperature-rise calculation in this document relate to specific arrangements of assembly in the conditions as defined. These arrangements and conditions do not cover all designs of assembly or the conditions in which some are installed. Where good practises are applied the calculation methods in this document can lead to conservative results.

Annex B, Annex C, Annex D, Annex E, Annex F, Annex H, Annex J and Annex K detail good practice that can lead to an improvement in thermal performance or some aspects not considered in the calculation method in this document. However, when using these additional considerations, to ensure a defined performance of an assembly, further verification, e.g. test, shall be performed.

### 6.2 Guidance on the effects of an uneven power distribution

The aim of Annex B is to determine the temperature-rise where there is not an even power distribution within an assembly using as a starting point the temperature-rise of a reference design or calculation in accordance with Clause 5.

### 6.3 Guidance on the additional temperature-rise effect due to solar radiation

In case of outdoor assemblies that are subject to direct sunlight, solar irridiance can significantly increase internal air temperature-rise and require a derating of the rated currents of the assembly. See Annex C.

## 7 Evaluation of the design

It shall be determined whether the equipment within the assembly can operate satisfactorily at the relevant calculated internal air temperature-rise.

If it is not so, the parameters will have to be changed and the calculation repeated.

**Table 1 – Method of calculation, application, formulas and characteristics**

| 1 | 2 | 3 | 4 | 5 [a] | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Calculation formulae | | | Enclosure | | Characteristics | | | | | Characteristic curve |
| Effective cooling surface $A_e$ | Temperature-rise of air | | Effective cooling surface $A_e$ | | Factors | | | | Exponent | Plotting of temperature-rise characteristics |
| | At mid-height of the enclosure | At (internal) top of enclosure | | | $b$ see | $k$ see | $d$ see | $c$ see | $x$ | |
| $A_e = \Sigma (A_o \times b)$<br>(1) | $\Delta t_{0,5} = k \times d \times p^x$<br>(2) | $\Delta t_{1,0} = c \times \Delta t_{0,5}$<br>(3) | >1,25 m$^2$ | Enclosure without ventilation openings | Table 3 | Figure 3 | Table 4 | Figure 4 | 0,804 | See 5.3.5.2 |
| | | | | Enclosure with ventilation openings | | Figure 5 | Table 5 | Figure 6 | 0,715 | |
| | | | ≤1,25 m$^2$ | Enclosure without ventilation openings | | Figure 7 | $d$=1 | Figure 8 | 0,804 | See 5.3.5.3 |

[a] For enclosure with ventilation openings with effective surface $A_e$ ≤ 1,25 m$^2$ the criteria of enclosures without ventilation openings can be used.

For symbols, units and designations, see Table 2.

For method of calculation, see also the examples given in Annex A.

### Table 2 – Symbols, units and designations

| Symbol | Unit | Designation |
|---|---|---|
| $A_o$ | $m^2$ | Surfaces of external sides of enclosure |
| $A_b$ | $m^2$ | Enclosure base surface |
| $A_e$ | $m^2$ | Effective cooling surface of enclosure |
| $A_s$ | $m^2$ | Surface area, which can transport heat (usually excluding the bottom area) |
| α | $W/m^2K$ | Heat transfer coefficient (includes conduction and radiation of heat) |
| $b$ | – | Surface factor |
| $c$ | – | Temperature distribution factor |
| $c_p$ | J/kg*K | Heat capacity (of air) |
| $d$ | – | Temperature-rise factor for internal horizontal partitions inside enclosure |
| $f$ | – | Height/base factor |
| $g$ | – | Height/width factor |
| $h$ | m | Enclosure height |
| $k$ | – | Enclosure constant |
| $n$ | – | Number of internal horizontal partitions (up to five partitions) |
| $P$ | W | Effective power loss of equipment installed inside enclosure (determined according to Annex G) |
| $P_{890}$ | W | Calculated power dissipation of the enclosure according to this document, without considering natural ventilation |
| $P_{fan}$ | W | Power losses dissipated by forced ventilation |
| $P_v$ | W | Effective power losses of conductors |
| $P_w$ | W | Total dissipated power |
| ρ | $kg/m^3$ | Mass density (of air) at $T_a$ |
| $V$ | $m^3/s$ | Volume flow rate of the air flow through the enclosure |
| $S_{air}$ | $cm^2$ | Cross-section of air inlet openings |
| $T_a$ | °C | Ambient temperature |
| $T_{int}$ | °C | Temperature inside the enclosure |
| $T_{int,max}$ | °C | Maximum temperature allowed inside the enclosure (limited e.g. by devices) |
| $w$ | m | Enclosure width |
| $x$ | – | Exponent |
| $\Delta t$ | K | Temperature-rise of air inside enclosure in general |
| $\Delta t_{0,5}$ | K | Temperature-rise of air at (internal) mid-height of enclosure |
| $\Delta t_{0,75}$ | K | Temperature-rise of air at (internal) three quarters height of enclosure |
| $\Delta t_{1,0}$ | K | Temperature-rise of air at (internal) top of enclosure |

### Table 3 – Surface factor *b* according to the type of installation

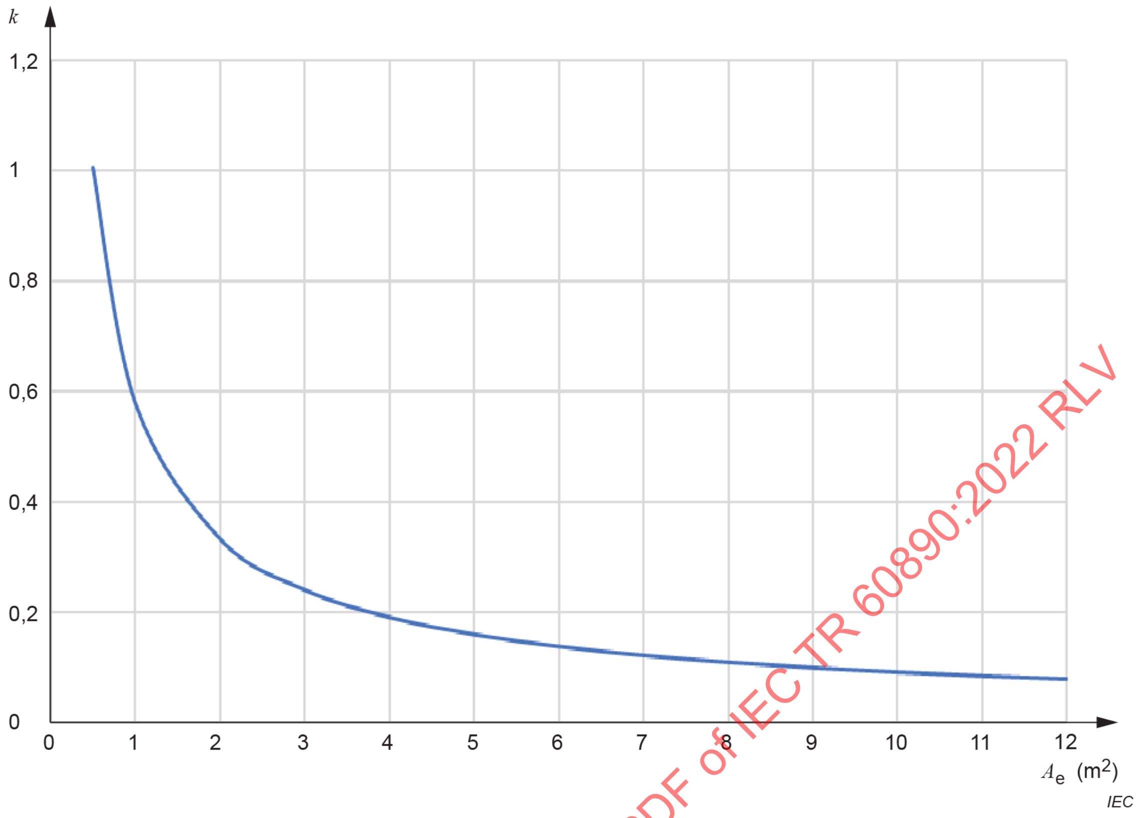
| Type of installation | Surface factor<br>*b* |
|---|---|
| Exposed top surface | 1,4 |
| Covered top surface, e.g. of built-in enclosures | 0,7 |
| Exposed side faces, e.g. front, rear and side walls | 0,9 |
| Covered side faces, e.g. rear side of wall-mounted enclosures | 0,5 |
| Side faces of central enclosures | 0,5 |
| Floor surface | not taken into account |
| Fictitious side faces of sections (see 5.3) which have been introduced only for calculation purposes are not taken into account | |

### Table 4 – Factor *d* for enclosures without ventilation openings and with an effective cooling surface $A_e$ > 1,25 m$^2$

| Number of horizontal partitions *n* | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Factor *d* | 1,00 | 1,05 | 1,15 | 1,30 | 1,45 | 1,55 |
| NOTE Alternative factor *d* values than those of Table 4 can be used according to comparison with test results of similar configurations. | | | | | | |

### Table 5 – Factor *d* for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$

| Number of horizontal partitions *n* | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Factor *d* | 1,00 | 1,05 | 1,10 | 1,15 | 1,2 | 1,25 |
| NOTE Alternative factor *d* values than those of Table 5 can be used according to comparison with test results of similar configurations. | | | | | | |



**Key**

$A_e$ effective cooling surface (see 5.3.2)

$k$ enclosure constant (see 5.3.3)

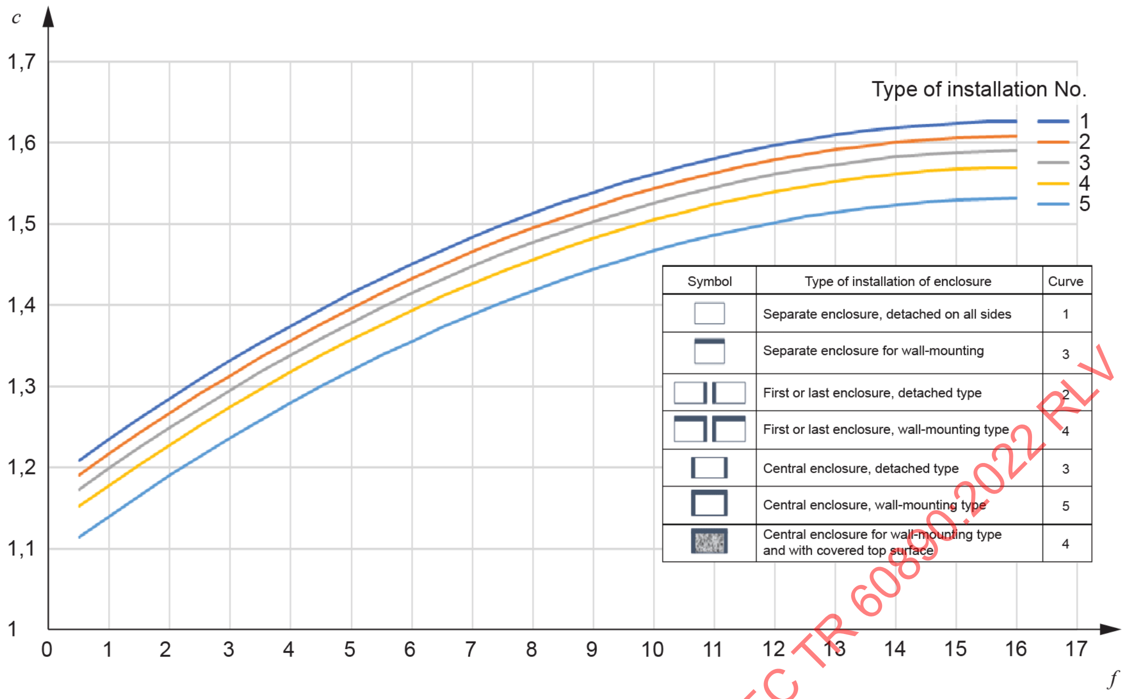
NOTE See Table 6 for the algebraic expression related to the curve.

**Figure 3 – Enclosure constant $k$ for enclosures without ventilation openings, with an effective cooling surface $A_e > 1{,}25\ m^2$**

Boundary conditions: the factor $A_e$ shall be higher than 1,25 and not exceed 12.

**Table 6 – Equation for Figure 3**

| Variable | Algebraic expression |
|---|---|
| $k$ | $k = 0{,}58 \times (A_e)^{-0{,}795}$ |
| **Key**<br>$A_e$ effective cooling surface (m²)<br>$k$ enclosure constant | |



| Symbol | Type of installation of enclosure | Curve |
|---|---|---|
| ▭ | Separate enclosure, detached on all sides | 1 |
| ▭ | Separate enclosure for wall-mounting | 3 |
| ▭ ▭ | First or last enclosure, detached type | 2 |
| ▭ ▭ | First or last enclosure, wall-mounting type | 4 |
| ▭ | Central enclosure, detached type | 3 |
| ▭ | Central enclosure, wall-mounting type | 5 |
| ▨ | Central enclosure for wall-mounting type and with covered top surface | 4 |

IEC

**Key**

*f* height/base factor (see 5.3.4)

*c* temperature distribution factor (see Figure 6 and Figure 8)

NOTE See Table 7 for the algebraic expressions related to the curves.

Boundary conditions: the factor *f* shall be higher than 0,3 and not exceed 16.

Figure 4 – Temperature distribution factor $c$ for enclosures without ventilation openings and with an effective cooling surface $A_e$ > 1,25 m$^2$

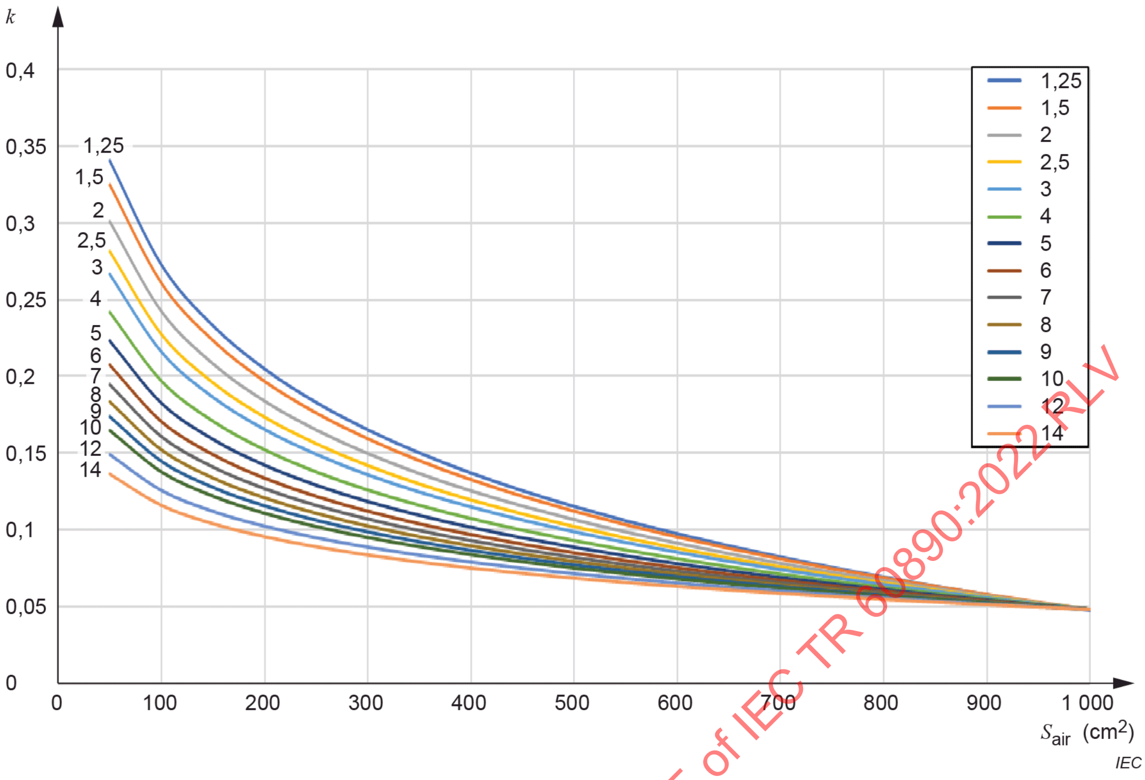
### Table 7 – Equations for Figure 4

| Installation type | Algebraic expressions |
|---|---|
| 5 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,087 |
| 4 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,125 |
| 3 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,146 |
| 2 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,164 |
| 1 | $c$ = -0,001 7 × $f^2$ + 0,055 × $f$ + 1,182 |

**Key**

*c* temperature distribution factor

*f* height / base factor; $0,3 \leq f \leq 16$. If *f* exceeds 16 then *c* should be calculated with *f* equal 16.



**Key**

$S_{air}$ cross-section of the corresponding air outlet openings

$k$ enclosure constant (see 5.3.3)

Boundary conditions: the factor $S_{air}$ shall be equal or higher than 10 cm$^2$ and not exceed 1 000 cm$^2$.

**Figure 5 – Enclosure constant $k$ for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$**

**Table 8 – Equations for Figure 5**

| Variable | Algebraic expressions |
|---|---|
| A$k$ | A$k$ = 2,83 × 10$^{-2}$ × ln($A_e$) – 10,39 × 10$^{-2}$ |
| B$k$ | B$k$ = 19,52 × 10$^{-2}$ × ln($A_e$) – 76,56 × 10$^{-2}$ |
| $k$ | $k$ = A$k$ × ln ($S_{air}$) – B $k$ |

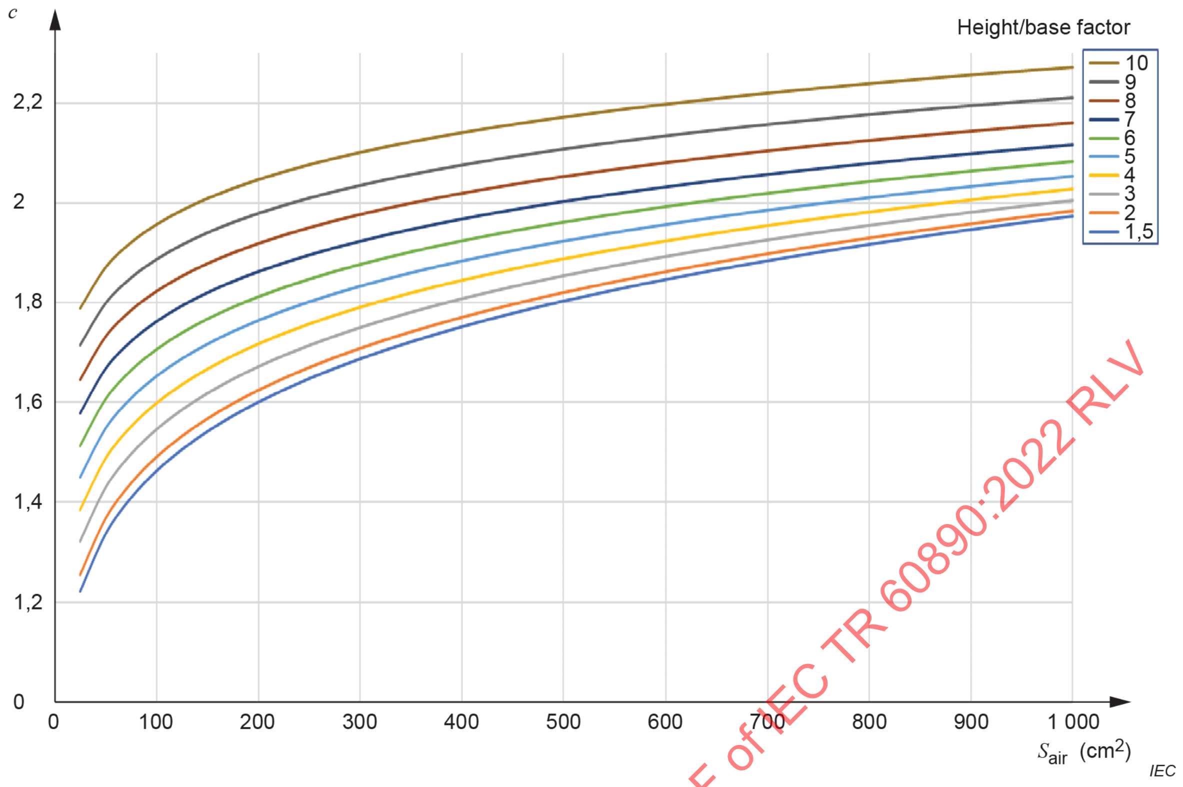
**Key**

$A_e$ effective cooling surface (m$^2$)

$S_{air}$ cross-section of air inlet openings (cm$^2$)

$k$ enclosure constant

A$k$ and B$k$ are intermediary variables to calculate the enclosure constant $k$.



**Key**

$S_{air}$ cross-section of the corresponding air outlet openings, cross-section of the corresponding air outlet should be at least 1,1 times that of the air inlet openings

$c$ temperature distribution factor

NOTE 1 See Table 9 for the algebraic expressions related to the curves.

NOTE 2 Height/base factor $f$, see 5.3.4.

Boundary conditions: the factor $S_{air}$ shall be equal or higher than 10 cm$^2$ and not exceeding 1 000 cm$^2$.

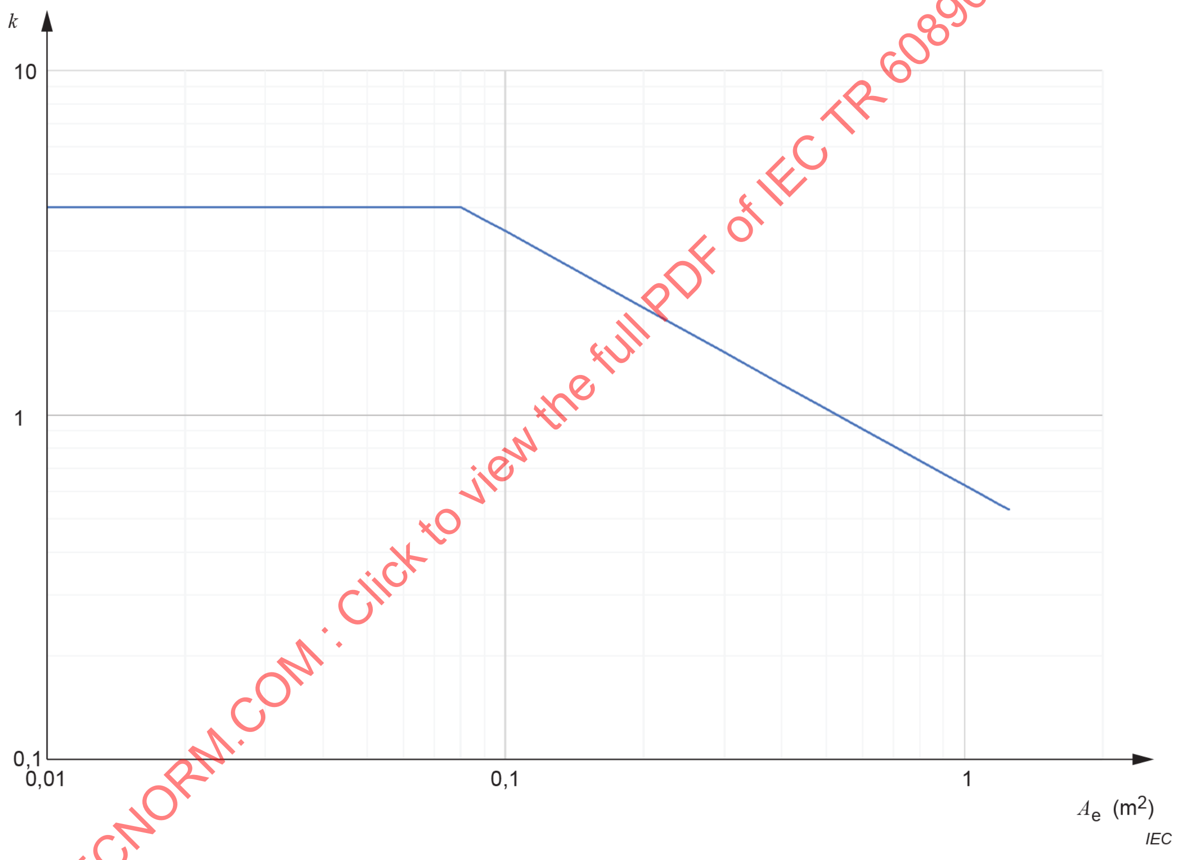
Figure 6 – Temperature distribution factor $c$ for enclosures with ventilation openings and an effective cooling surface $A_e$ > 1,25 m$^2$

**Table 9 – Equations for Figure 6**

| Variable | Algebraic expressions |
|---|---|
| $\mathrm{A}c$ | $\mathrm{A}c = 7{,}6 \times f + 69$ |
| $\mathrm{B}c$ | $\mathrm{B}c = 5{,}1 \times 10^{-4} \times f^{2} - 1{,}35 \times 10^{-2} \times f + 14{,}931 \times 10^{-2}$ |
| $c$ | $c = 0{,}01 \times \mathrm{A}c \times S_{\mathrm{air}} \wedge \mathrm{B}c$ |

**Key**

| | |
|---|---|
| $c$ | temperature distribution factor |
| $f$ | height / base factor |
| $S_{\mathrm{air}}$ | cross-section of air inlet opening (cm$^2$) |
| $\mathrm{A}c$ and $\mathrm{B}c$ | are intermediary variables to calculate the temperature distribution factor $c$. |



**Key**

| | |
|---|---|
| $A_e$ | effective cooling surface (see 5.3.2) |
| $k$ | enclosure constant (see 5.3.3) |

NOTE See Table 10 for the algebraic expression related to the curve.

Boundary conditions: the factor $A_e$ shall not exceed 1,25.

**Figure 7 – Enclosure constant *k* for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1{,}25$ m$^2$**

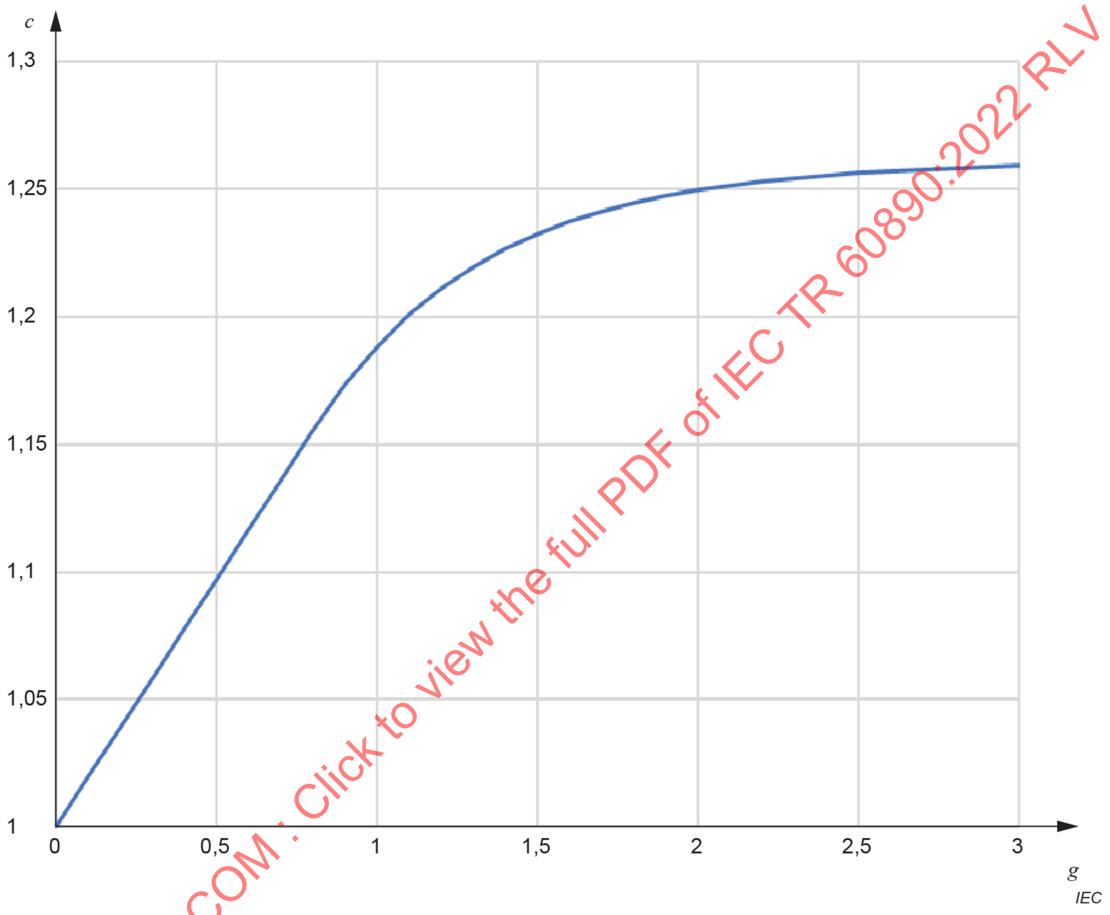
## Table 10 – Equation for Figure 7

| Variable | Algebraic expression |
|---|---|
| $k$ | $k$ = 4 if ($A_e$ < 0,08) else 0,626 × $(A_e)^{-0.737}$) |

**Key**

$A_e$ effective cooling surface ($m^2$)

$k$ enclosure constant



**Key**

$g$ height/width factor (see 5.3.4)

$c$ temperature distribution factor

NOTE See Table 11 for the algebraic expressions related to the curve.

Boundary conditions: the factor $g$ shall be equal or higher than 0 and not exceed 3.

**Figure 8 – Temperature distribution factor $c$ for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1{,}25\ m^2$**

### Table 11 – Equation for Figure 8

| Variable | Algebraic expressions |
|---|---|
| $c$ | If $g$ > 0,814 7, $c$ = 0,324 055 × (1- e(-1,882 7 × $g$ +0,385 79)) + 0,936 43<br>Else, $c$ = 0,193 54 × $g$ + 1 |

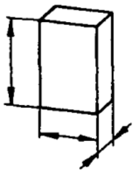
**Key**

$c$ temperature distribution factor

$g$ height / width factor

| Calculation of temperature-rise of air inside enclosure |
|---|

| | | | |
|---|---|---|---|
| Customer/plant | | | |
| Type of enclosure | | | |
| Relevant dimensions for temperature-rise | height | mm | Type of installation: |
| | width | mm | Ventilation openings: yes/no |
| | depth | mm | Number of horizontal partitions: |

| Effective cooling surface |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m$^2$ | | m$^2$ |
| | | 2 | 3 | 4 | 5 |
| | Top | | | | |
| | Front | | | | |
| | Rear | | | | |
| | Left-hand side | | | | |
| | Right-hand side | | | | |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m$^2$ | Not exceeding 1,25 m$^2$ |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4)<br>= ______________________ = | $g = \frac{h}{w}$ (see 5.3.4)<br>= ______________________ = |

| | | |
|---|---|---|
| Air inlet openings | cm$^2$ | |
| Enclosure constant $k$ | | |
| Factor for horizontal partitions $d$ | | |
| Effective power loss $P$ | W | |
| $P^x = P^{\cdots}$ | | |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | |
| Temperature distribution factor $c$ | | |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | |

Characteristic curve:

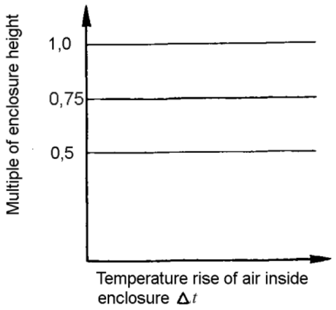


Figure 9 – Calculation of temperature-rise of air inside enclosures

# Annex A
(informative)

# Examples for the calculation of the temperature-rise of air inside enclosures

## A.1 Example 1

Single enclosure with exposed side faces without ventilation openings and without internal horizontal partitions (see Figure A.1).

Effective power loss of equipment installed in the enclosure: $P$ = 300 W.

Dimensions in millimetres

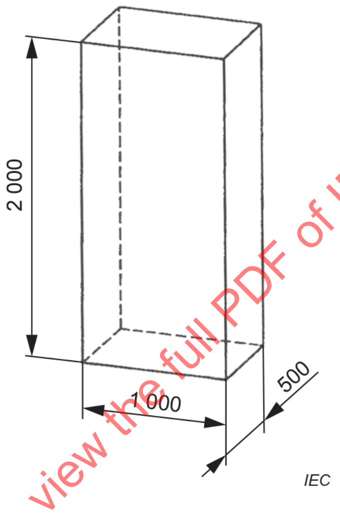


**Figure A.1 – Example 1, calculation for an enclosure with exposed side faces without ventilation openings and without internal horizontal partitions**

*Calculation* (for values see template, Figure A.2 on Example 1):

- The effective cooling surface $A_e$ is determined according to 5.3.2.

  The individual surfaces are calculated from the enclosure dimensions, and the surface factor $b$ is taken from Table 3.

- The temperature-rise of air $\Delta t_{0,5}$ is determined according to 5.3.3.

  Formula (2) from column 2 of Table 1:

$$\Delta t_{0,5} = k \times d \times P^x \qquad (A.1)$$

Factor $k$ according to column 7 of Table 1 with $A_e$ > 1,25 m$^2$, as shown in Figure 3:

for $A_e$ = 6,64 m$^2$: $k$ = 0,129

Factor $d$ according to column 8 of Table 1 with $A_e$ > 1,25 m$^2$, as specified in Table 4:

with number of horizontal partitions = 0: $d$ = 1,0

Effective power loss (as specified) $P$ = 300 W.

Exponent $x$ from column 10 of Table 1 with $A_e$ > 1,25 m$^2$: $x$ = 0,804

With these values entered into the Formula (A.1), the following result is obtained:

$$\Delta t_{0,5} = k \times d \times P^{x} = 0{,}129 \times 1{,}0 \times 300^{0{,}804}$$

$$\Delta t_{0,5} = 12{,}63 \text{ K} \approx 12{,}6 \text{ K}$$

– The temperature-rise of air $\Delta t_{1,0}$ is determined according to 5.3.4.

Formula (3) from column 3 of Table 1:

$$\Delta t_{1,0} = c \times \Delta t_{0,5} \qquad \text{(A.2)}$$

Factor $c$ according to column 9 of Table 1 with $A_e > 1{,}25$ m$^2$, as shown in Figure 4:

$$f = \frac{h^{1{,}35}}{A_b} = \frac{2{,}2^{1{,}35}}{1{,}0 \times 0{,}5} = 5{,}80$$

Curve 1 of Figure 4 follows:

$$c = 1{,}44$$

With this value entered into Formula (A.2), the following result is obtained:

$$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1{,}44 \times 12{,}63 = 18{,}18 \text{ K} \approx 18{,}2 \text{ K}$$

– The temperature-rise characteristic curve is determined for enclosures with $A_e > 1{,}25$ m$^2$, in accordance with 5.3.5.2 (see Figure A.2 in the template on Example 1).

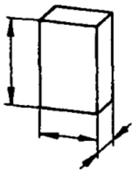
– The evaluation of the design is made in accordance with Clause 7.

It shall be verified whether the equipment installed in the enclosure is capable of functioning satisfactorily at the specified currents and calculated temperature-rises, considering the ambient air temperature (see Note of Clause 1).

If this is not so, the parameters shall be changed and the calculation repeated.

| Calculation of temperature-rise of air inside enclosure |
|---|

| | | | | | |
|---|---|---|---|---|---|
| Customer/plant **Example 1** | | | | | |
| Type of enclosure **Single enclosure** | | | | | |
| Relevant dimensions for temperature-rise | Height | **2 200** | mm | Type of installation: | **Detached on all sides** |
| | Width | **1 000** | mm | Ventilation openings: | ~~yes~~/**no** |
| | Depth | **500** | mm | Number of horizontal partitions: | **0** |

| |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m² | | m² |
| | | 2 | 3 | 4 | 5 |
| Effective cooling surface | Top | **1,0 × 0,5** | **0,5** | **1,4** | **0,7** |
| | Front | **1,0 × 2,2** | **2,2** | **0,9** | **1,98** |
| | Rear | **1,0 × 2,2** | **2,2** | **0,9** | **1,98** |
| | Left-hand side | **0,5 × 2,2** | **1,1** | **0,9** | **0,99** |
| | Right-hand side | **0,5 × 2,2** | **1,1** | **0,9** | **0,99** |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | **6,64** |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m² | Not exceeding 1,25 m² |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4) | $g = \frac{h}{w}$ (see 5.3.4) |
| $= \frac{\mathbf{2{,}2^{1,35}}}{\mathbf{1 \times 0{,}5}} = \mathbf{5{,}8}$ | $= \underline{\qquad\qquad} =$ |

| | | |
|---|---|---|
| Air inlet openings | cm² | **0** |
| Enclosure constant $k$ | | **0,129** |
| Factor for horizontal partitions $d$ | | **1** |
| Effective power loss $P$ | W | **300** |
| $P^x = P^{\cdots}$ | | **98,09** |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | **12,63 K ≈ 12,6 K** |
| Temperature distribution factor $c$ | | **1,44** |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | **18,18 K ≈ 18,2 K** |

Characteristic curve:

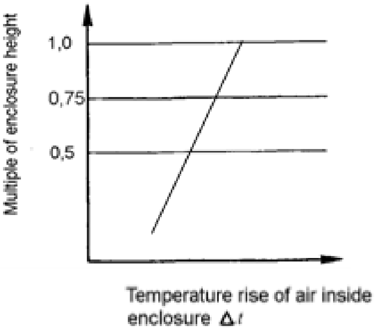


**Figure A.2 – Example 1, calculation for a single enclosure**

## A.2 Example 2

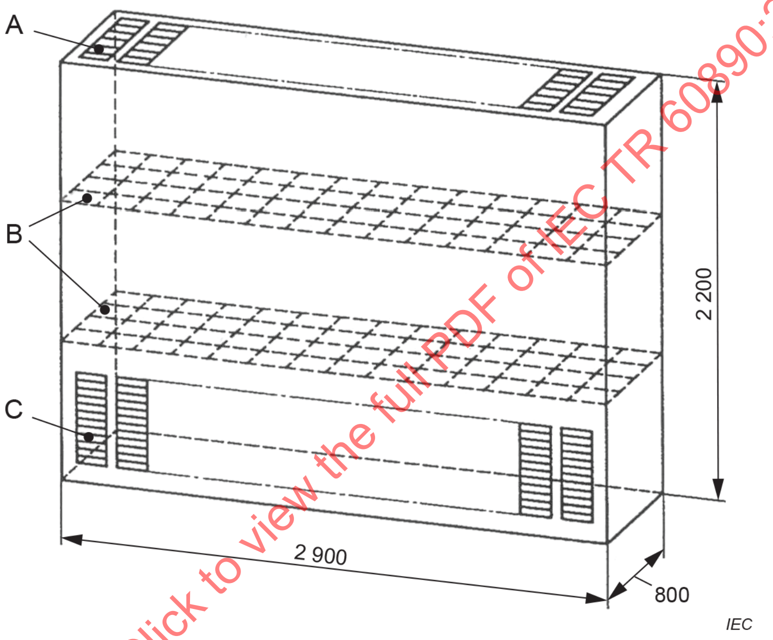
Enclosure for wall-mounting with ventilation openings

cross-section of air inlet openings = 1 220 cm$^2$
cross-section of air outlet openings = 1 800 cm$^2$

with two horizontal partitions inside the enclosure. Each horizontal partition, for example perforated plate, has ventilation openings, the cross-sectional areas of which exceed 50 % of the enclosure cross-section (see Figure A.3 and Figure A.4).

Effective power loss of equipment installed in the enclosure $P$ = 2 200 W.

Dimensions in millimetres



**Key**

A Air outlet openings

B Horizontal partitions with ventilation openings, for example perforated plate

C Air inlet openings

**Figure A.3 – Example 2, calculation for an enclosure for wall-mounting with ventilation openings**

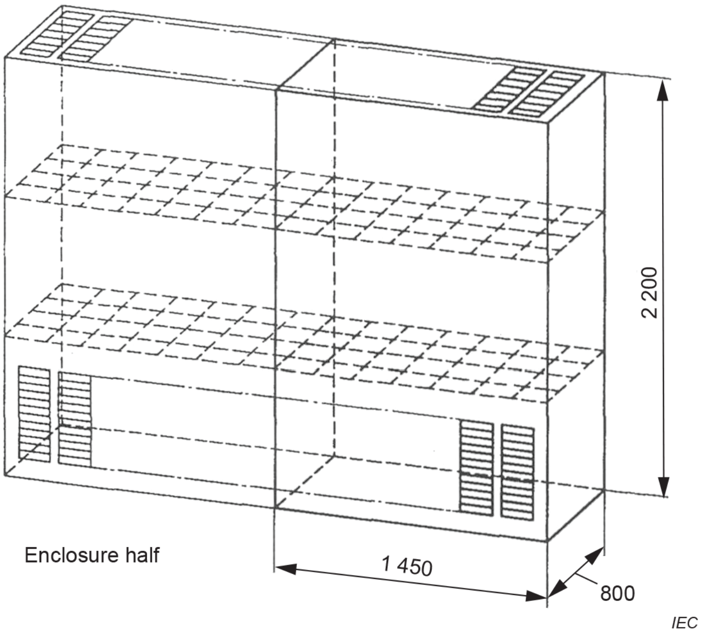
Calculation (for values see template Figure A.5 on Example 2):

Given an expected cooling surface of the enclosure is more than 11,5 m$^2$ and has an enclosure width exceeding 1,5 m, the entire enclosure shall be divided, for calculation purposes, into sections (partial enclosures) as indicated in 5.3.1. To simplify the procedure, as no structural divisions are available, the entire enclosure is, in this example, divided into two equal sections (enclosure halves). The power losses and ventilation openings are supposed to be evenly distributed in both parts (enclosure halves) so that for the calculation they are divided by two.

The calculation is carried out for only one enclosure half, the result being applicable to the other half.

– Necessary information according to 5.2 for one half of the enclosure

Dimensions in millimetres



Enclosure for wall-mounting with air inlet openings

$$= \frac{1\,220}{2} = 610\ \text{cm}^2$$

With air outlet openings

$$= \frac{1\,800}{2} = 900\ \text{cm}^2$$

With two horizontal partitions, for example perforated plate

Effective power loss

$$= \frac{2\,200}{2} = 1\,100\ \text{W}$$

**Figure A.4 – Example 2, calculation for one enclosure half**

– The effective cooling surface of each enclosure half is determined according to 5.3.2.

The individual surfaces are calculated from the enclosure dimensions, and the surface factor $b$ is taken from Table 3.

The dividing surface between the two enclosure halves which has been obtained as a result of the fictitious division, is not taken into account in accordance with Table 3.

– The temperature-rise of air $\Delta t_{0,5}$ is determined according to 5.3.3.

Formula (2) from column 2 of Table 1

$$\Delta t_{0,5} = k \times d \times P^x \tag{A.3}$$

Factor $k$ according to column 7 of Table 1 and $A_e$ > 1,25 m$^2$, as shown in Figure 5.

For 610 cm$^2$ air inlet openings and $A_e$ = 7,674 m$^2$: $k$ = 0,071 3

Factor $d$ according to column 8 of Table 1 and $A_e$ > 1,25 m$^2$ as specified in Table 5 with two horizontal partitions: $d$ = 1,10

Effective power loss (as specified) $P$ = 1 100 W

Exponent $x$ from column 10 of Table 1 with $A_e$ > 1,25 m$^2$: $x$ = 0,715

With these values entered into the above Formula (A.3), the following result is obtained:

$$\Delta t_{0,5} = k \times d \times P^x = 0{,}071 \times 1{,}10 \times 1\,100^{0{,}715}$$

$$\Delta t_{0,5} = 11{,}72\ \text{K} \approx 11{,}7\ \text{K}$$

– The temperature-rise of air $\Delta t_{1,0}$ is determined according to 5.3.4.

Formula (3) from column 3 of Table 1

$$\Delta t_{1,0} = c \times \Delta t_{0,5} \tag{A.4}$$

Factor $c$ according to column 9 of Table 1 and $A_e$ > 1,25 m$^2$, as shown in Figure 6.

$$f = \frac{h^{1,35}}{A_b} = \frac{2{,}2^{1,35}}{1{,}45 \times 0{,}8} = 2{,}50$$

Figure 6 shows that, for 610 cm$^2$ air inlet openings:

$$c = 1{,}88$$

With these values entered into Formula (A.4), the following result is obtained:

$$\Delta t_{1,0} = c \times \Delta t_{0,5} = 1{,}87 \times 11{,}67 = 22{,}03 \text{ K} \approx 22 \text{ K}$$

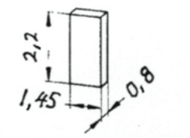
- The temperature-rise characteristic curve is determined for enclosures with $A_e$ > 1,25 m$^2$, in accordance with 5.3.5.2 (see Figure A.5 in the template on Example 2).
- The evaluation of the design is made in accordance with Clause 7.

  It shall be verified whether the equipment installed in the enclosure is capable of functioning satisfactorily at the specified currents and calculated temperature-rises, considering the ambient air temperature (see Note of Clause 1).

  If this is not so, the parameters shall be changed and the calculation repeated.

| Calculation of temperature-rise of air inside enclosure |
|---|

| | | | | |
|---|---|---|---|---|
| Customer/plant | **Example 2** | | | |
| Type of enclosure | **2 200 high, 2 900 wide, 800 deep; divided in 2 enclosure halves** | | | |
| Relevant dimensions for temperature-rise | Height | **2 200** | mm | Type of installation: **Wall-mounting** |
| | Width | **1 450** | mm | Ventilation openings: **yes/~~no~~** |
| | Depth | **800** | mm | Number of horizontal partitions: **0** |

| Effective cooling surface |  | Dimensions | $A_o$ | Surface factor $b$ according to Table 3 | $A_o \times b$ (column 3) × (column 4) |
|---|---|---|---|---|---|
| | | m × m | m² | | m² |
| | | 2 | 3 | 4 | 5 |
| | Top | **1,45 × 0,8** | **1,16** | **1,4** | **1,624** |
| | Front | **1,45 × 2,2** | **3,19** | **0,9** | **2,871** |
| | Rear | **1,45 × 2,2** | **3,19** | **0,5** | **1,595** |
| | Left-hand side | **0,8 × 2,2** | **1,76** | **0,0** | **–** |
| | Right-hand side | **0,8 × 2,2** | **1,76** | **0,9** | **1,584** |
| | $A_e = \Sigma(A_o \times b)$ = Total | | | | **7,674** |

| With an effective cooling surface $A_e$ | |
|---|---|
| Exceeding 1,25 m² | Not exceeding 1,25 m² |
| $f = \frac{h^{1,35}}{A_b}$ (see 5.3.4)<br>$= \frac{\mathbf{2,2^{1,35}}}{\mathbf{1,45 \times 0,8}}$ = **2,5** | $g = \frac{h}{w}$ (see 5.3.4)<br>= ______ = |

| | | |
|---|---|---|
| Air inlet openings | cm² | **610** |
| Enclosure constant $k$ | | **0,071 3** |
| Factor for horizontal partitions $d$ | | **1,1** |
| Effective power loss $P$ | W | **2 200/2 = 1 100** |
| $P^x = P^{\cdots}$ | | **149,48** |
| $\Delta t_{0,5} = k \times d \times P^x$ | K | **11,72 K ≈ 11,7 K** |
| Temperature distribution factor $c$ | | **1,88** |
| $\Delta t_{1,0} = c \times \Delta t_{0,5}$ | K | **22,03 K ≈ 22 K** |

Characteristic curve:

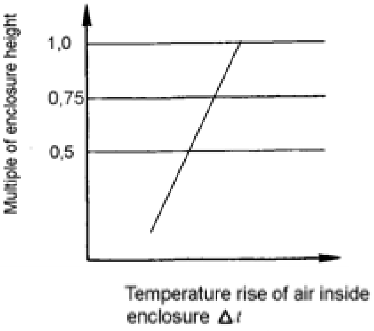


**Figure A.5 – Example 2, calculation for an enclosure for wall-mounting with ventilation openings**

# Annex B
(informative)

# Guidance on the effects of an uneven power distribution

## B.1 Horizontal partition

For typical assemblies used in the distribution of electrical energy, functional units are installed one above another with horizontal partitions in between each of the functional units. Typical arrangements are shown in the examples of Figure B.1

**a) Assembly without ventilation openings, and less than 50 % perforation in horizontal partition**

**b) Assembly with ventilation openings, and at least 50 % perforation in horizontal partition**

**Key**

1 to 5 horizontal separation

**Figure B.1 – Examples of assemblies with horizontal partitions**

The calculation method in Clause 5 assumes:

1) there is an approximately even power distribution within the assembly; and,
2) with a ventilated assembly, the area of the ventilation openings (perforation) in each horizontal partition is at least 50 % of the horizontal cross-section of the compartment to ensure a sufficient air flow through the compartment.

In some assemblies, for example certain designs of motor control centre (MCC), these conditions are not fulfilled; uneven power distribution can result from one circuit having a much higher power dissipation per unit volume (circuit with highest power dissipation) than the others and/or the perforation in horizontal partitions can be much less than 50 % of the horizontal cross section of the compartment.

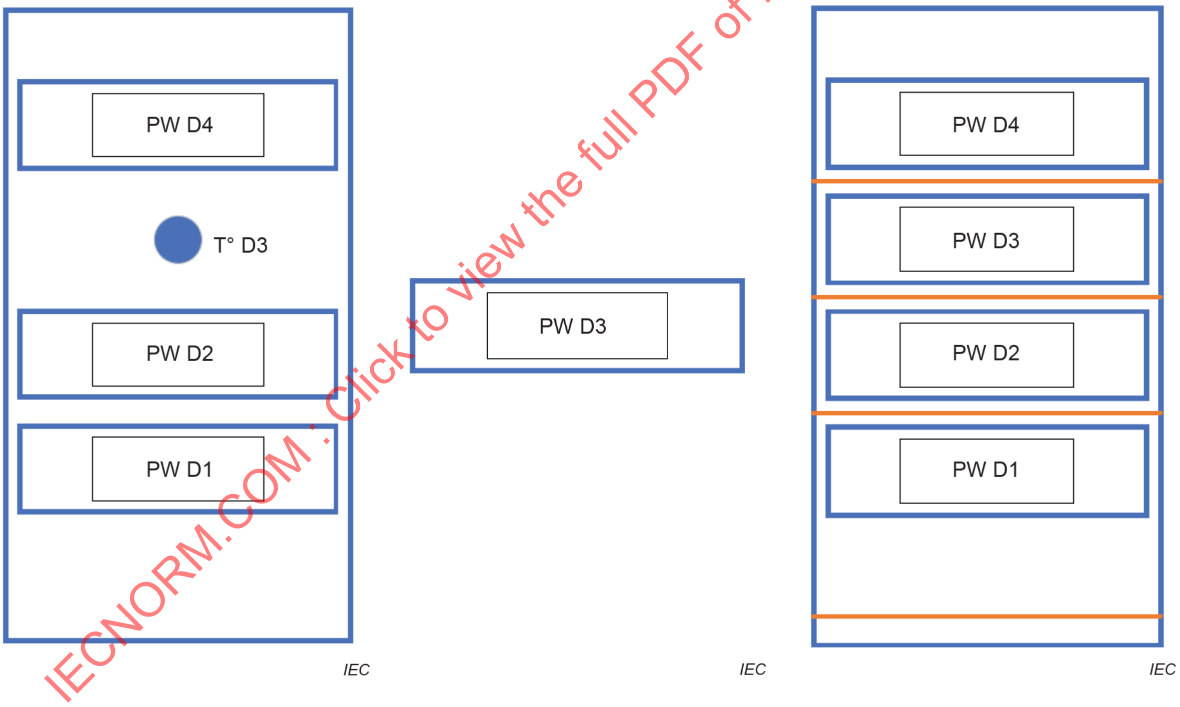
## B.2 Calculation of internal air temperature-rise for assemblies with ventilation openings with even power distribution and less than 50 % perforation in horizontal partitions

Assuming the power dissipation is approximately even within the section being considered, calculate the temperature-rise assuming there is no ventilation. The air temperature at any position within the section shall not exceed the maximum operating temperature allowed for the components at their respective positions within the section. See 5.4.

## B.3 Calculation of internal air temperature-rise with an uneven power distribution

This is a two or three step process.

- First step: determine the air temperature-rise at the point in the section where the higher-power dissipation circuit shall be located. This can be by measurement of the temperature in a reference design temperature-rise test. Alternatively, using this document calculate the air temperature-rise at the point in the section where the higher-power circuit shall be located considering the total power loss of the section, excluding the power loss of the higher-power circuit. For example, T° D3 in Figure B.2.
- Second step: assume the higher-power circuit (PW D3 in Figure B.2) is enclosed as it is within the assembly by using factors for covered surfaces in Table 3, and calculate the air temperature within PW D3 in accordance with 5.3, using the dimensions of PW D3 and assuming an ambient temperature T° D3. The calculated air temperature within PW D3 shall not exceed the maximum operating temperature allowed for the components installed within PW D3. See 5.4.
- Third step: if the higher-power circuit is located at the top position, this step is not required. If the higher-power circuit is not located at the top of its section using 5.3, calculate the air temperature within the section considering the total power loss within the section. The calculated air temperature at any position within the section shall not exceed the maximum operating temperature allowed for the components at their respective positions. See 5.4.



**Step 1: calculate the air temperature within the section without the higher-power circuit**

**Step 2: calculate the air temperature within the higher-power circuit assuming an air temperature of T° D3**

**Step 3: calculate the air temperature within the section including the higher-power circuit**

**Figure B.2 – Temperature-rise verification of a higher-power circuit**