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Corrosion of metals and alloys — Classification of low corrosivity of indoor atmospheres —

Part 1:
Determination and estimation of indoor corrosivity

Corrosion des métaux et alliages — Classification de la corrosivité faible des atmosphères d'intérieur —

Partie 1: Détermination et estimation de la corrosivité des atmosphères d'intérieur

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 262, *Metallic and other inorganic coatings, including for corrosion protection and corrosion testing of metals and alloys*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 11844-1:2006), which has been technically revised. The main changes compared with the previous edition are as follows:

- a reference to the ISO 16000 series in Clause 7 has been added;
- a model that estimates the indoor concentration and deposition of pollutants originating from outdoors has been added;
- lead has been included as a standard specimen with high sensitivity to vapour organic acids.

A list of all parts in the ISO 11844 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Metals, alloys and metallic coatings are subject to atmospheric corrosion under the impact of air humidity, especially when gaseous and solid substances of atmospheric pollution co-impact. Corrosivity data are of fundamental importance for derivation of suitable corrosion protection, or for evaluation of serviceability of metal elements of a product.

ISO 9223 classifies the atmospheric environment into six corrosivity categories.

Low corrosivity indoor atmospheres are indoor atmospheres with C 1 (very low) or C 2 (low) corrosivity categories in accordance with ISO 9223.

The classification in ISO 9223 is too broad for some purposes in low corrosivity indoor atmospheres, e.g. places where electronic devices, sophisticated technical products, or works of art and historical objects are stored.

For such purposes, it is necessary to subdivide the corrosivity categories C 1 (very low) and C 2 (low) into the indoor corrosivity categories given in this document.

The evaluation of low corrosivity indoor atmospheres can be accomplished by direct determination of corrosion attack of selected metals (see ISO 11844-2) or by measurement of environmental parameters (see ISO 11844-3) that can cause corrosion on metals and alloys.

This document describes general procedures for derivation and estimation of indoor corrosivity categories.

The aim of this document is to characterize indoor atmospheric environments of low corrosivity that can affect metals and metallic coatings during storage, transport, installation or operational use, to set a consistent way of indoor corrosivity classification, and to prescribe procedures for derivation and estimation of indoor corrosivity categories.

A general approach to the classification of corrosivity of indoor atmospheres is given in the scheme shown in Figure 1.

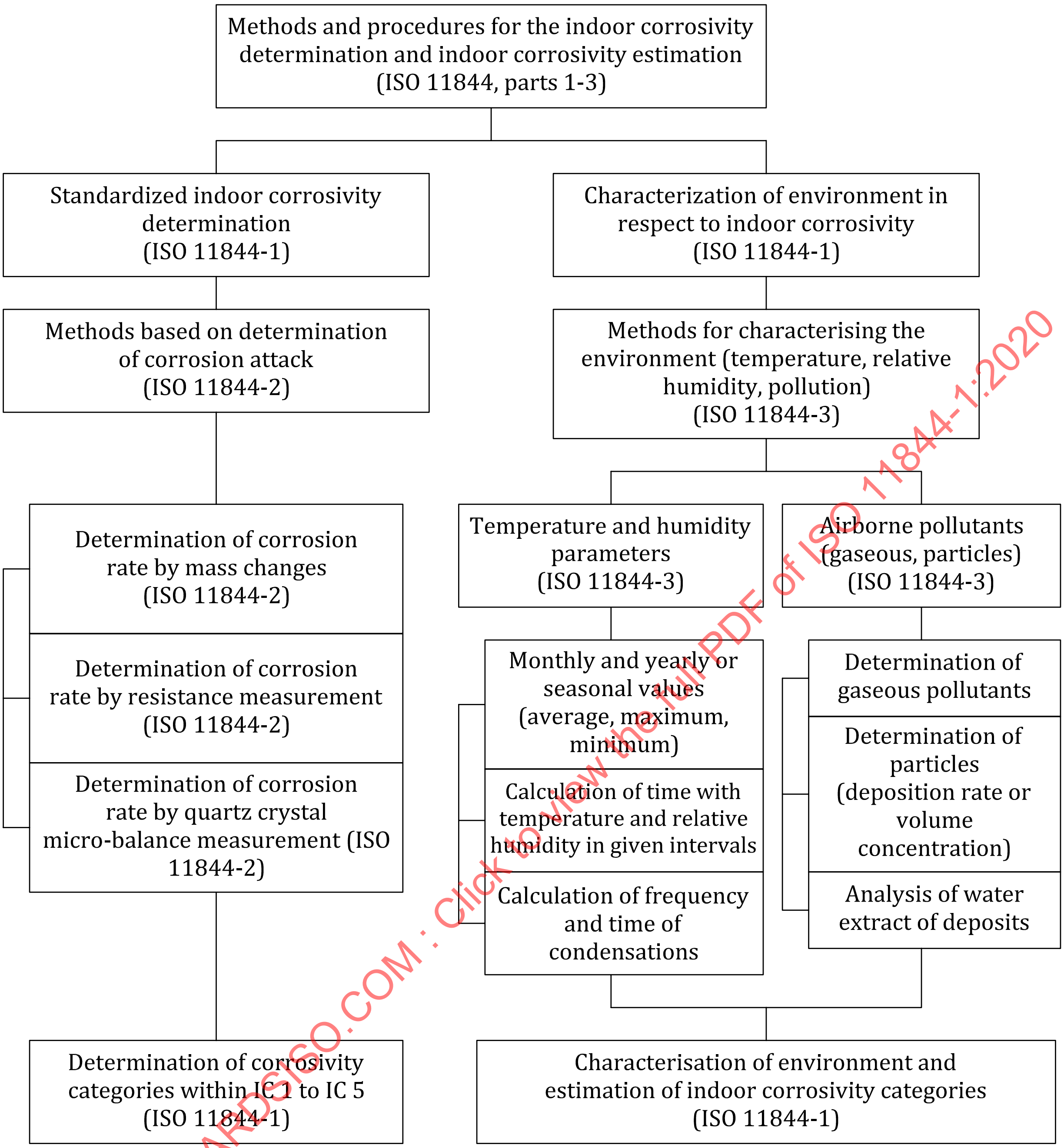


Figure 1 — Scheme for classification of low corrosivity of indoor atmospheres

Corrosion of metals and alloys — Classification of low corrosivity of indoor atmospheres —

Part 1:
Determination and estimation of indoor corrosivity

1 Scope

This document establishes a classification of low corrosivity of indoor atmospheres.

It specifies the reference metals for which a corrosion attack after a defined exposure period is used for determining corrosivity categories of indoor atmospheres of low corrosivity.

It defines corrosivity categories of indoor atmospheres according to corrosion attack on standard specimens.

It indicates important parameters of indoor atmospheres that can serve as a basis for an estimation of indoor corrosivity.

The selection of a method for the determination of corrosion attack, description of standard specimens, exposure conditions and evaluation are given in ISO 11844-2. The measurement of environmental parameters affecting indoor corrosivity is given in ISO 11844-3.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
climate
statistics of temperature, humidity, atmospheric pressure, wind, rainfall, and other meteorological elements in a given location over a long period of time

[SOURCE: EN 15759-1:2011, 3.1]

3.2
atmosphere
mixture of gases, aerosols and particles that surrounds a given material, object or structure

3.3
indoor atmosphere
environment [combined effect of *climate* (3.1) and *atmosphere* (3.2)] inside a box, a room or a building

3.4
microclimate
climate (3.1) of a small area, specific rooms, part of building, etc., which may be different from that in the general region

3.5
temperature-humidity complex
combined effect of temperature and relative humidity on the *corrosivity of the atmosphere* (3.10)

[SOURCE: ISO 9223:2012, 3.4]

3.6
time of wetness
period when a metallic surface is covered by adsorptive and/or liquid films of electrolyte to be capable of causing atmospheric corrosion

[SOURCE: ISO 9223:2012, 3.5]

3.7
atmospheric pollution
specific corrosion-active substances, gases or suspended particles in the air (both natural and the result of human activity)

3.8
corrosion system
system consisting of one or more metals and those parts of the environment that influence corrosion

[SOURCE: ISO 8044:2020, 3.4, modified — Note 1 to entry has been deleted.]

3.9
corrosivity
ability of an environment to cause corrosion of a metal in a given *corrosion system* (3.8)

[SOURCE: ISO 8044:2020, 3.14]

3.10
corrosivity of atmosphere
ability of the atmosphere to cause corrosion in a given *corrosion system* (3.8)

EXAMPLE Atmospheric corrosion of a given metal or alloy.

[SOURCE: ISO 9223:2012, 3.1, modified — An example has been added.]

4 Symbols and abbreviated terms

IC	indoor corrosivity
r_{corr}	corrosion rate derived from mass-loss measurement after an exposure of one year
r_{mi}	rate of mass increase after an exposure of one year

5 Classification of corrosivity

5.1 General

The corrosivity of indoor atmospheres can be classified either by a determination of the corrosion attack on standard specimens of selected standard metals as given in Clause 6 or, where this is not possible, by an estimation of corrosivity based on the knowledge of humidity, temperature and pollution conditions as described in Clause 7 and Annexes B, C and D.

Estimation of corrosivity as described in 7.2 and Annexes C and D can lead to wrong conclusions. Therefore, the determination of corrosivity by the measurement of the corrosion attack on standard specimens is strongly recommended.

5.2 Categories of indoor corrosivity

For the purpose of this document, indoor atmospheres are classified into five corrosivity categories denoted IC 1 to IC 5. The classification is given in Table 1.

Table 1 — Corrosivity categories of indoor atmospheres

Indoor corrosivity category	
IC 1	Very low indoor corrosivity
IC 2	Low indoor corrosivity
IC 3	Medium indoor corrosivity
IC 4	High indoor corrosivity
IC 5	Very high indoor corrosivity

6 Determination of indoor atmospheric corrosivity

The determination of corrosivity of indoor atmospheres is based on measurements of corrosion attack on standard specimens of five reference metals after an exposure for one year in accordance with ISO 11844-2. From the mass loss or mass increase, the indoor corrosivity category for each metal is determined from Table 2.

In indoor environments when the all conditions (temperature, humidity, air pollutions) vary only in range of ±5 % from average value, the exposure period should be shorter, e.g. one month only. Preferably, this month should represent the most corrosive period of the year.

Metals complement each other in the classification of indoor corrosivity for a given environment.

7 Characterization of indoor atmospheres with respect to indoor corrosivity

7.1 General

Environmental characteristics are informative and allow assessment of specific corrosion effects with regard to individual metals and metallic coatings.

The ISO 16000 series deals with indoor air measurements describing the sampling strategy, including the conditions to be observed for particular substances or groups of substances, such as the dependence of indoor air pollution concentrations on atmospheric humidity or temperature or other effects. ISO 16000-1:2004, Table A.1, summarizes the most important types of indoor environment and gives examples of the sources that can be encountered in them. The list is not, of course, fully comprehensive because of the large number of possibilities. ISO 16000-1:2004, Table B.1, shows the sources of indoor air pollutants and the most important substances emitted. ISO 16000-1:2004, Table C.1, lists substances frequently detected and their possible sources. The ISO 16000 series does not cover all indoor air pollutants significant for indoor atmospheric corrosivity.

Methods for the characterization and measurement of environmental parameters of indoor atmospheres are given in ISO 11844-3.

This method of corrosivity estimation is, in many cases, oversimplified and can give misleading results.

An estimation of corrosivity is based on:

- climatic influences (outdoor situation including pollution);

- indoor microclimate influences;
- indoor gaseous and particle pollution.

The corrosivity of an indoor atmosphere increases with higher humidity and depends on the type and level of pollution.

Important characteristics are frequency of variation of relative humidity (RH) and temperature (T) in intervals, and frequency and time of condensation.

An indoor environment is rarely static, since the concentration of any substance can be constantly altered by the strength of the source, human activity, ventilation rate, external or internal climatic conditions, chemical reactions and possible sinks (e.g. sorption by surfaces and furnishings). In addition, the composition of indoor air can vary within and between rooms, and be less homogeneous than the outdoor air surrounding the building.

Indoor atmospheres are polluted by the components from external and internal sources. Typical pollutants are SO_2, NO_2, O_3, H_2S, Cl_2, NH_3, HCl, HNO_3, Cl^-, NH_4^+, organic acids, aldehydes and particles (see Annex B). Due to the permanent exchange between indoor and outdoor air caused by infiltration and ventilation processes, it may be important to supplement indoor air measurements with a simultaneous measurement of the outdoor air [if possible, at the same level (floor) of the building]. The outdoor air samples should be taken in the vicinity of the building but not closer than 1 m. In making such measurements, it should be remembered that vertical concentration gradients can occur, e.g. for the components of vehicle exhaust gases in street canyons.

The air exchange of a building, whether it is due to mechanical ventilation, natural ventilation or infiltration, can have a significant influence on the indoor atmosphere. The model estimates the indoor concentration and deposition of pollutants originating from outdoors was derived for the steady-state indoor/outdoor (I/O) relation of various gaseous pollutions in buildings, as shown by Formula (1):

$$\mathrm{I/O}=\frac{C_i}{C_o}=\frac{n}{n+v_d\left(\frac{A}{V}\right)} \quad (1)$$

where

C_i is the indoor concentration of pollutant (in µg.m^{-3});

C_o is the outdoor concentration of pollutant (in µg.m^{-3});

n is the air exchange rate (in h^{-1});

v_d is the deposition velocity (in m.h^{-1});

A is the inside surface area of room (in m^2);

V is the volume of room (in m^3).

The typical I/O ratio of sulfur dioxide is approximately 0,50. The typical I/O ratio of nitrogen dioxide is in the range of 0,60 to 0,80. There are exceptions: at sites with a low air exchange rate, or with chemical air-filtration, the I/O ratio can be less than 0,10. The matching I/O concentration ratios for ozone show the same trend, with the typical I/O ratio below 0,7, and half of these I/O ratios even below 0,20.

For indoor conditions, volatile organic acids such as formic acid (HCOOH), acetic acid (CH_3COOH) and propionic acid (CH_3CH_2COOH) can have a significant influence on indoor corrosivity. Carboxylic acids in the atmosphere can exist as anthropogenic and/or biogenic air pollution, from automotive exhaust, biomass combustion for domestic and industrial heating, vegetation, organic coatings or emanating from the oceans. Other sources can be the photochemical oxidation of organic species in air or water.

Corrosion for many of the metals is significantly influenced by the synergistic effects of different pollutants.

Metals and metallic coatings have their own specific corrosion behaviour in indoor atmospheres (see Annex C).

7.2 Estimation of indoor corrosivity

7.2.1 The characterization of the environment summarized in a guideline (see Annex D) forms a basis for indoor corrosivity estimation. A description of typical environments related to the estimation of indoor corrosivity categories is presented in Table D.3.

7.2.2 Important factors of indoor corrosion are defined as the highest levels of measured environmental parameters and as a description of other and specific environmental influences affecting the indoor corrosion of metals.

7.2.3 The determination of indoor corrosivity categories is illustrated in Tables 2 and 3.

NOTE 1 The specification of standard specimens of carbon steel, zinc, copper, silver and lead, and the procedures for evaluation of the mass change is given in ISO 11844-2.

NOTE 2 Corrosion rate measurements by mass loss determination of standard specimens (see Table 2) are preferably used for higher indoor corrosivity categories. Also, in atmospheres where a high deposition of particles is expected, the mass loss determination is preferred.

NOTE 3 An approximate relation between the corrosivity categories in this document and severity levels in ANSI/ISA-S71.04-1985 is given in Annex A.

NOTE 4 The upper limit of corrosivity category IC 3 corresponds roughly to the upper limit of corrosivity category C 1 in accordance with ISO 9223.

NOTE 5 The upper limit of corrosivity category IC 5 corresponds roughly to the upper limit of corrosivity category C 2 in accordance with ISO 9223.

Table 2 — Classification of corrosivity of indoor atmospheres based on corrosion rate measurements by mass loss determination of standard specimens

Corrosivity category		Corrosion rate (r_{corr}) (mg.m^{-2}. a^{-1})				
		Carbon steel	**Zinc**	**Copper**	**Silver**	**Lead**
IC 1	Very low indoor	$r_{corr} \leq 70$	$r_{corr} \leq 50$	$r_{corr} \leq 50$	$r_{corr} \leq 170$	$r_{corr} \leq 40$
IC 2	Low indoor	$70 < r_{corr} \leq 1\,000$	$50 < r_{corr} \leq 250$	$50 < r_{corr} \leq 200$	$170 < r_{corr} \leq 670$	$40 < r_{corr} \leq 150$
IC 3	Medium indoor	$1\,000 < r_{corr} \leq 10\,000$	$250 < r_{corr} \leq 700$	$200 < r_{corr} \leq 900$	$670 < r_{corr} \leq 3\,000$	$150 < r_{corr} \leq 400$
IC 4	High indoor	$10\,000 < r_{corr} \leq 70\,000$	$700 < r_{corr} \leq 2\,500$	$900 < r_{corr} \leq 2\,000$	$3\,000 < r_{corr} \leq 6\,700$	$400 < r_{corr} \leq 700$
IC 5	Very high indoor	$70\,000 < r_{corr} \leq 200\,000$	$2\,500 < r_{corr} \leq 5\,000$	$2\,000 < r_{corr} \leq 5\,000$	$6\,700 < r_{corr} \leq 16\,700$	$700 < r_{corr} \leq 1\,600$

Table 3 — Classification of corrosivity of indoor atmospheres based on rate of mass increase measured with standard specimens

Corrosivity category		Rate of mass increase (r_{mi}) (mg.m^{-2}. a^{-1})				
		Carbon steel	**Zinc**	**Copper**	**Silver**	**Lead**
IC 1	Very low indoor	$r_{mi} \leq 70$	$r_{mi} \leq 50$	$r_{mi} \leq 25$	$r_{mi} \leq 25$	—
IC 2	Low indoor	$70 < r_{mi} \leq 700$	$50 < r_{mi} \leq 250$	$25 < r_{mi} \leq 100$	$25 < r_{mi} \leq 100$	—
IC 3	Medium indoor	$700 < r_{mi} \leq 7\,000$	$250 < r_{mi} \leq 700$	$100 < r_{mi} \leq 450$	$100 < r_{mi} \leq 450$	—
IC 4	High indoor	$7\,000 < r_{mi} \leq 50\,000$	$700 < r_{mi} \leq 2\,500$	$450 < r_{mi} \leq 1\,000$	$450 < r_{mi} \leq 1\,000$	—
IC 5	Very high indoor	$50\,000 < r_{mi} \leq 150\,000$	$2\,500 < r_{mi} \leq 5\,000$	$1\,000 < r_{mi} \leq 2\,500$	$1\,000 < r_{mi} \leq 2\,500$	—

Annex A
(informative)

Relationship between ISO, IEC and ISA classification systems

ISO 9223, IEC 60654-4:1987, Appendix B, and ANSI/ISA S71.04-1985 all include corrosion rate determination for classifying environmental conditions.

ISO 9223 gives corrosivity categories based on corrosion of carbon steel, zinc, copper and aluminium, expressed as mass loss after one year of exposure.

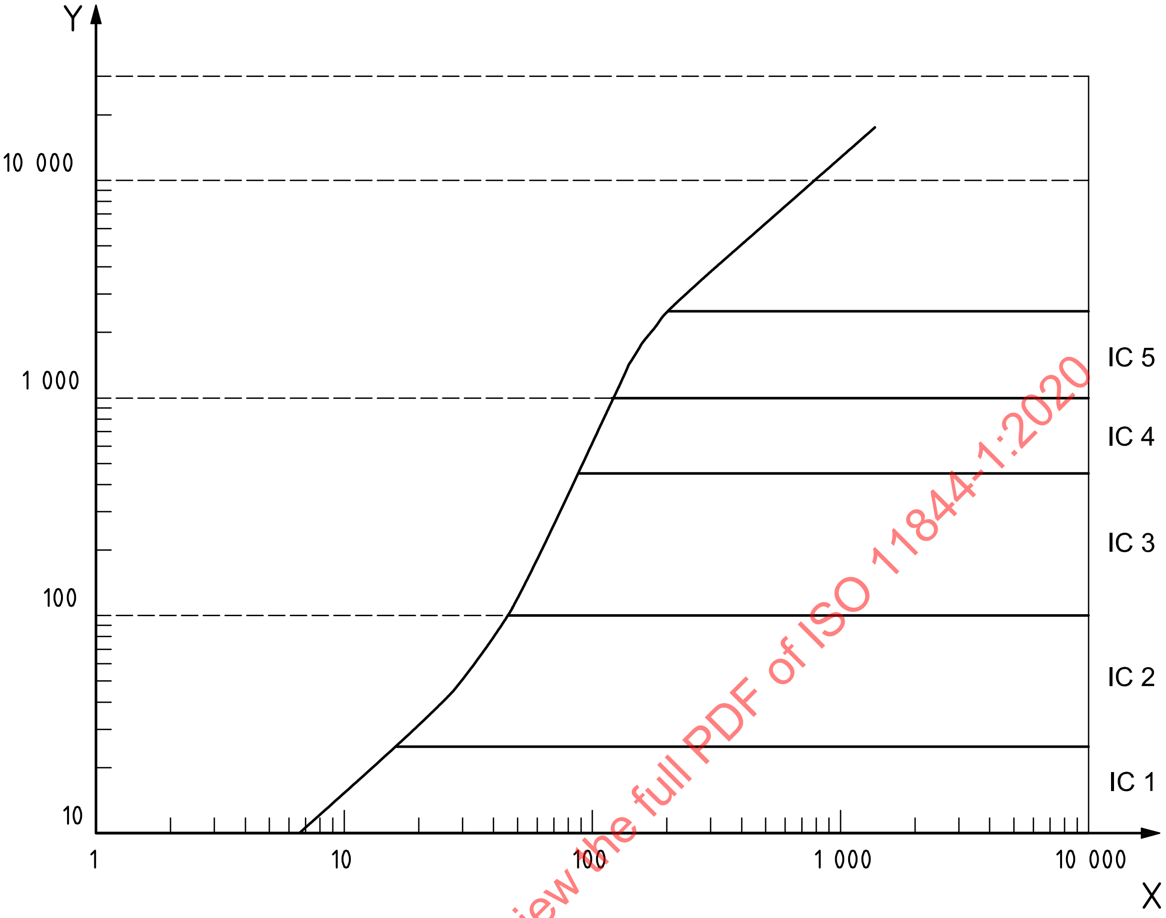
IEC 60654-4:1987, Appendix B, classifies the reactivity of the environment, measuring corrosion film thickness on copper after 30 days of exposure.

ANSI/ISA S71.04-1985 gives severity levels, based on copper corrosion measured as corrosion film thickness after 30 days of exposure.

In order to compare these classification systems, the corrosion figures for copper have been selected, since copper is the only metal common to all the standards. All the corrosion rates have been transformed to the same unit. The corrosion figures given in the standards are first expressed as mass increase. Then, for the IEC and ISA standards, mass increase after 30 days of exposure has been transformed into one year. The correlation between 30 days and one year of exposure is graphically presented in Figure A.1. The graphical representation is based on expressions given in the IEC and ISA standards.

NOTE Extrapolation in time is not very reliable and cannot be done at all for low corrosion rates.

In Figure A.2, the classification systems of the different standards have been compared. The comparison is based on the copper corrosion rate, assuming that CuO, $Cu_4SO_4(OH)_6$ and Cu_2S are the predominant corrosion products. The corrosion rate figures given in the standards have all been transformed to copper mass increase after one year of exposure.

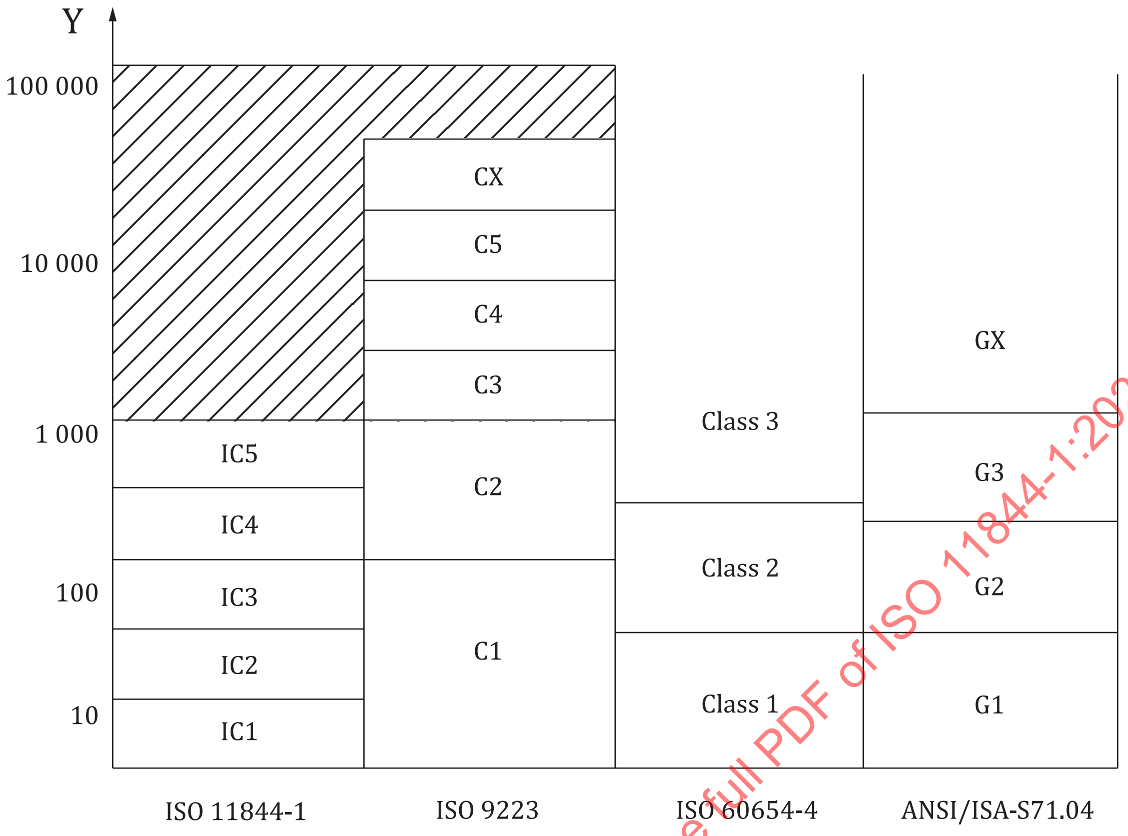


Key

X mass increase after 30 days of exposure (in mg.m^{-2})

Y mass increase after one year of exposure (in mg.m^{-2})

Figure A.1 — Copper mass increase, transformation between 30 days and one year of exposure



Key

Y mass increase after one year of exposure (in mg.m^{-2})

▨ the hatched area is not covered by ISO 9223

Figure A.2 — Copper corrosivity classification according to ISO, IEC and ISA

Annex B
(informative)

Outdoor and indoor concentrations of some of the most important pollutants in different types of environments

Table B.1 — Outdoor and indoor concentrations of some of the most important pollutants in different types of environments

Pollutant	Concentration (yearly average value) (μg.m^{-3})		
	Outdoor		Indoor
SO_2	Rural:	2 to 15	Non-process rooms: (30 to 70) % lower than the outdoor level Process rooms: up to 2 000
	Urban:	10 to 100	
	Industrial:	50 to 250	
NO_2	Rural:	2 to 20	Only minor differences between outdoor and indoor concentrations of NO_2 unless close to the source
	Urban:	20 to 150	
O_3		20 to 80	Indoor concentrations are in most cases lower than outdoor (1 to 30)
H_2S	Normally:	1 to 5	No reduction indoors Indoor levels are sometimes higher than outdoor levels
	Industry and animal shelter:	20 to 250	
Cl_2	Normally very low concentrations:	0,1	Indoor concentrations are in most cases low In process rooms in the pulp and paper industry, observed concentration up to 50
	At industry plants:	up to 20	
Cl^-	Depending on geographic situation	0,1 to 200	Lower levels than in outdoor air Reduction depending on the ventilation and filter systems used
NH_3	Normally low concentrations:	< 20	No reduction indoors
	Close to source:	up to 3 000	
Organic components (acids, aldehydes)	Specific industrial pollution		Important component of indoor pollution Indoor concentrations are affected by human activity
Particles (dust deposits)	Rural:	largely inert components	Non-process rooms: large reduction of outdoor concentration Process rooms: specific aggressive components
	Urban and industrial:	corrosion-active components (SO_4^{2-}, NO_3^-, Cl^-, lime)	
Soot	Rural:	< 5	Non-process rooms: large reduction of outdoor concentration Process rooms: up to 200
	Urban and industrial:	up to 75	

Annex C
(informative)

General characterization of metal corrosion in indoor atmospheres

The basic corrosion factors in indoor atmospheres are temperature-humidity characteristics and pollution by gaseous and solid substances. The importance of humidity and temperature impact cannot be expressed simply and consistently by the time of wetness defined in ISO 9223.

The type of indoor atmosphere can significantly influence the level of each atmospheric parameter, as well as its distribution. Pollutant concentrations are generally lower in indoor environments, except for cases of internal sources of pollution.

The basic characteristics of indoor atmospheric environments, in relation to corrosion of metals and various ways of their exploitation, are represented by the following.

a) Temperature, humidity and their changes cannot be derived directly from outdoor conditions and depend on the purpose of use of the indoor space in unconditioned atmospheric environments.

b) The transfer of outdoor pollution depends on the way and degree of sheltering, or on controlled conditions in indoor atmospheric environments (filtration, conditioning).

c) The successive accumulation of particles and increasing conductivity of deposits of water extracts can change corrosivity indoors for longer exposures.

d) It is difficult to determine a relatively limited selection of the decisive corrosion factors and levels of their importance in indoor atmospheric environments. One of the reasons for this is that metals show specific sensitivity to individual environmental factors.

Besides emissions formed outside objects, indoor environments are polluted by substances formed by:

- releases from building and construction materials and materials used for furnishing and the equipment of interiors;
- human presence, i.e. products of metabolism including: formaldehyde, formic acid, acetic acid, butyric acid, acetone, ammonia, carbon dioxide, hydrogen sulphide, water vapour, microbes, etc.;
- human activity, i.e. products related to operation and production activities.

The corrosion behaviour of important technical metals is specified in Table C.1.

Table C.1 — Corrosion behaviour of basic metal representatives in indoor environments

Metal	Corrosion behaviour
Steel	— spontaneously forms oxides and other corrosion products with a limited protecting ability — very sensitive to relative humidity and to sulfur dioxide — the central transformations are the oxidation and reduction processes that link Fe^{2+} and Fe^{3+} — indoors, at a relative humidity higher than about 50 %, multilayers of water will be adsorbed; particularly with the presence of particles, a corrosion process analogous to the outdoor corrosion process with a lower corrosion rate will occur
Zinc	— the indoor zinc corrosion rate is affected by relative humidity; the deposited particles or the zinc corrosion products appear to absorb sufficient moisture to stimulate the chemical degradation process — sensitive to indoor organic compounds, mainly vapour organic acids — synergistic effect of SO_2, NO_x and O_3 — indoor zinc tarnish often starts at points where dust particles have settled on the surface; indoor zinc surfaces have upon them adherent particles containing large concentrations of chloride and sulfate ions — the indoor corrosion rates can be constrained to negligible levels by maintaining moderate relative humidity
Copper	— sensitive to relative humidity — sensitive to a broad range of pollutants — significant influence of H_2S (even in RH < 50 %), sulfur dioxide — little influence of NO_x, Cl_2 and NH_3 — synergistic effect of SO_2, NO_x and O_3 — the most severe contaminant is hydrogen sulphide, especially in combination with chlorine — in atmospheres where SO_2 + H_2S the corrosion effect of H_2S is inhibited by SO_2 — the corrosion rate shows a general decrease with time (particularly for the less corrosive sites)
Silver	— corrodes indoors at approximately equivalent rates to outdoors; the reason for this similarity is supposed to be the independence of the silver corrosion rate on relative humidity — the corrosion rate is governed by the reaction with H_2S rather than by the acidity of the pollutants — the corrosion rate is dependent on the reduced sulfur pollutant concentration — gaseous hydrogen peroxide, which is sometimes present, strongly accelerates corrosion — quite sensitive to molecular chlorine — insensitive to organic acids and has not been reported to be reactive towards most other common indoor organic molecules and radicals — the corrosion rate decreases with time

Table C.1 *(continued)*

Metal	Corrosion behaviour
Nickel	— in mild environments, suffers very little from visible corrosion — corrosion is, to a large extent, determined by the sulfur dioxide content and relative humidity — the corrosion rate in complex polluted environments is strongly dependent on the relative humidity — synergistic effect of SO_2, NO_x and O_3
Lead	— quite reactive to common atmospheric gases; forming of insulating corrosion-product layers — indoor exposures produce lead carboxylates — relatively sensitive to air pollution by organic aldehydes and acids
Tin	— quickly covered with an oxide film with good corrosion protection — chlorine and chloride-containing pollutants attack thin oxide films and increase the rate of corrosion, especially in combination with high levels of relative humidity
Aluminium	— rapidly forms an insulating oxide layer — low rates of corrosion in most indoor environments — chloride ions stimulate localized attack on the surface — has the highest corrosion rate in environments characterized by high levels of chlorides in combination with high relative humidity
Gold	— as a very noble metal does not corrode in normal indoor environments — the corrosion behaviour of gold-plated surfaces is influenced by pollutants in a complex manner — if gold is used as a thin coating, pore corrosion can occur even in a rather mild environment — pore corrosion, resulting from corrosion of a nickel undercoating or of a copper substrate, is stimulated by high levels of relative humidity, chlorine, sulfur dioxide and hydrogen sulphide
Stainless steel	— in mild environments without a corrosion effect — deposits of particles with ionic components (chlorides) can stimulate a localized attack on surfaces in environments with higher relative humidity